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THE MANUFACTURE OF ELECTRICAL CONDENSERS.

BY

G. F. MANSBRIDGE, Member.

(*Paper received January 8, and read in London on May 7, 1908.*)

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Although electrical condensers are among the oldest devices in the art of applied electricity, it is only within the last few years that the demand for them has assumed any degree of commercial importance. Until about 1898 practically the whole of the supplies were for telegraph work, but since then the situation has been entirely changed by the great development of the telephone service of the world, and particularly of the common-battery system, in which condensers play a modest but important *rôle.* The magnitude of the present demand may be gauged from the fact that the aggregate output of condensers in Europe and America during 1907 is estimated at the once-inconceivable capacity of 5 farads.

With manufacture established on this scale, economy in production is imperative, and the skilled hand of the 'nineties, who laboriously assembled or "built" his 1 or 2 microfarads per day, has given place to the machine hand who, with less physical distress, readily turns out one hundred times that quantity per diem. As a result the manufacturing costs have been so greatly reduced that condensers equal in quality to those produced ten years ago can now be purchased at approximately one-tenth the price. This reduction in cost has brought about a yet further increase in the demand, since it now pays to employ condensers for many services from which they were previously shut out by their high cost. Consequent, no doubt, upon the newness of the industry, very little seems to have been published in the way of precise physical, electrical, or manufacturing data, and the present paper is an attempt to deal with some of the technical points which seem to be of the most importance in the manufacture and use of condensers.

Throughout the paper the subject has been looked at chiefly from the point of view of the practician; the numerical data quoted must therefore be considered, not as figures obtained in a laboratory, but as representing the carefully digested results of workshop tests made in the ordinary course on large batches of condensers. These tests, though made with reasonable care, may not be of the high order of accuracy obtainable with tests of isolated specimens taken under laboratory conditions, but it is thought that their accuracy is sufficiently close for all ordinary purposes, and that they will be of practical value as representing the average of a very large number of results obtained under commercial conditions. The author has, moreover, no respect for five-figure results worked out on two-figure galvanometer deflections.

Many of the data are gleaned from the records of the Post Office factory at Mount Pleasant, Clerkenwell, London, E.C., and for permission to publish these the author has to acknowledge his indebtedness to Mr. J. W. Willmot, I.S.O., the Controller of the Factories' Department of the Post Office.

For convenience of description, the various types of condensers are considered separately. They fall naturally into four chief classes namely—

I. Mica.
II. Glass.
III. Paper or other fibrous material impregnated with wax, resin, oil, etc.
IV. Electrolytic cells.

I. *Mica Condensers.*—On account of the very high cost of mica sheet suitable for the work, condensers of this form are but little used.

Mica condensers, when well made, retain their capacity and insulation better than those made of paper, and they have also a higher dielectric strength for the same thickness, but the cost per microfarad is approximately ten times greater than that of paper condensers. Fortunately, the inductive capacity of mica is high (about twice that of paraffined paper), or the labour cost would be excessive, since the size of the sheets is limited to about 4 in. by 3 in., the cost of larger sheets of uniform thickness being prohibitive. A good working thickness is 0·0015 to 0·002 in., and if the material is carefully selected there is no necessity, for ordinary purposes, to use more than one sheet between consecutive foils. For purposes where mechanical strength in the condenser plate itself is of special advantage mica is very satisfactory, and for standards it is unrivalled. In standards the chief desiderata are:—

(1) Constant capacity with efflux of time.
(2) Constant capacity with varying temperature.
(3) High insulation and low absorption.

To obtain (1) it is necessary that the mica and tinfoil sheets be perfectly flat and free from inequalities, so that they will build up under pressure into a solid mass without flexure or mechanical strain; it is also necessary that in assembling the sheets all air-bubbles be excluded.

To obtain (2) advantage is taken of the fact discovered by Dr. Alexander Muirhead* that the mica sheets have a positive temperature coefficient if coated with shellac, and a negative temperature coefficient if coated with paraffin. By building a condenser in two sections, one treated with shellac and one with paraffin wax, the variation of capacity within ordinary limits of temperature can thus be brought practically to vanishing-point.

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* U.K. Patent 15337, 1891, A. Muirhead.

To obtain (3) it is necessary to use only selected sheets of the finest clear "ruby" mica, which must be uniform in thickness throughout the sheet, and free from cracks, veins, or flaws; spotted or "speckled" mica is useless for the purpose.* The shellac employed should be the finest button lac dissolved in absolute alcohol and carefully strained until perfectly free from suspended matter. The building up or assembling of the sheets of foil and mica may conveniently be done on a "hot plate," the greatest care being taken to exclude air-bubbles, grit, or excess of paraffin or shellac. The desiccation should be slow but thorough, and the temperature should not exceed 212° Fahr. The finished condenser should be carefully and not excessively pressed, and should be allowed to cool under pressure in the ordinary way.

II. *Glass Condensers.*—A few years ago the Leyden jar would not have called for comment in a "practical" paper, but the requirements of wireless telegraphy and X-ray work have latterly increased the importance of apparatus of this character, and there is now quite an appreciable trade in glass jars for this specific purpose. As is well known to wireless workers, Leyden jars, like other condensers, are prone to fail in use if at any point there is imperfect contact between the conductor and the dielectric, and to avoid this difficulty the best plan is to silverplate the glass. This may be done by precipitating metallic silver on to the glass in the form of a bright continuous film by the well-known method employed for silvering galvanometer mirrors, etc. The solution generally used is nitrate of silver which has been treated with ammonia until the precipitate first formed has been completely re-dissolved. The surface of the glass must be cleaned with the most scrupulous care before plating is attempted, or an imperfect coating will result. The silver coating should then be mechanically strengthened by a protecting layer of varnish, or it may be over-plated with copper.

An important development of this silver-plated Leyden jar is to be found in the Moscicki high-tension condenser recently placed on the market. A brief description of this condenser has already been made public, but it is thought that the apparatus is of sufficient interest to warrant detailed reference, and by the courtesy of Messrs. Isenthal & Co., of Mortimer Street, London, the author is able to exhibit a condenser of this form in a manner which will permit of the construction being readily seen. In the author's opinion this condenser represents the most satisfactory and practical high-tension condenser for commercial work which has been introduced up to the present.

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* An interesting memorandum on mica has recently been published by the United States Department of the Interior.

The failures of previous high-tension condensers were due to imperfect adaptation of the material to the requirements and to the inherent weakness or instability of the dielectric, and, as is well known, the working life of such condensers was invariably short. In the Moscicki condenser great technical skill has been shown in adapting the material so as best to meet the onerous conditions. An imperishable and highly stable material, glass, is used for the dielectric, a most intimate and complete contact is made between the conductor and the dielectric by chemical deposition of silver, excessive strains are avoided at the point of high dielectric stress (the edges) by suitably thickening the dielectric at this point, and the effects of local heating are minimised by water-cooling. The failures of high-tension condensers of other types have no doubt engendered a certain feeling of distrust in the minds of many station engineers, and it may be that this suspicion will take some time to eradicate. In view, however, of the large number of stations working with a power factor ranging about 0·75, and of the advantages to be gained by improving this power factor, the author would suggest that the question of installing a battery of modern glass condensers at such stations is worthy of more than passing consideration.

III. *Condensers with Paper or other Fibrous Dielectrics.*—Although this form of condenser has been employed for many years, there have been but few important changes in the process of manufacture until lately. The standard practice up to the last decade was to use separate sheets of tissue paper and separate sheets of thin metallic foil, and the method employed was to dry the paper by heat, then to transfer it to a bath of hot paraffin wax, and after due soaking to build up the condenser on a "hot plate," the paper being taken sheet by sheet from the bath of hot wax. At least two sheets of paper were used between consecutive foils, the alternate foils being bunched into two books in the well-known way. The paper used was of fine quality, giving only a minute percentage of ash on incineration, being free from grit, holes, specks, etc., and being neutral in chemical reaction. A good working thickness was 0·001 in. The metal foil was usually of tin, the thickness being about 0·0003 in.

Obviously this method of building condenser plates was slow, tedious, and expensive, and it had the further disadvantage that as the workmen who handled the material were exposed to a high temperature, the risk of contamination of the wax by emanations from the body was great; indeed, the difficulty was such a serious one that the manufacture of satisfactory condensers in very hot weather was practically impossible, and in London it often became necessary, on this account, to cease manufacture during the summer months. Even in cooler weather it was necessary to select workmen who were not prone to perspire freely, as only such men could be depended upon to produce condensers with satisfactory and permanent insulation. In consequence of this difficulty, the author found it of advantage to build up the condenser plates "dry" in a separate room and to desiccate and impregnate the condensers as a subsequent operation. By this arrangement practically all the handling was done under more favourable conditions in a cool shop, and the electrical results obtained were more satisfactory than under the old system, and at the same time the cost of manufacture was considerably reduced. The slow process of assembling the sheets one by one and of handling about 250 separate pieces to make up a 1-microfarad plate had, however, still to be reckoned with, and the percentage of failures through short circuit or low insulation was considerable, so that the labour cost remained an important factor.

The next step was in the direction of bringing down this high labour cost by reducing the number of pieces to be handled. The method adopted was to wind up into the form of a roll long strips of metal foil, two strips of paper being interposed between each foil—that is, six strips in all. This method, which was introduced to the Post Office by Sir John Gavey in 1899, had, however, difficulties of its own. Pure tin foil of the requisite thinness could not at that time be obtained in strips longer than a few feet, and the alternatives were: (1) to feed between the rolls of paper a series of strips of pure tin foil some 4 ft. long, each strip overlapping its predecessor by an inch or two so as to maintain continuity; or (2) to use an alloy of lead and tin which could be obtained in continuous lengths. The former was an awkward and unmechanical arrangement, and the latter had the disadvantage of producing a heavy and bulky condenser. Both methods also involved a considerable proportion—rarely less than 10 or 15 per cent.—of short circuits in the finished plates brought about by grit in the foil or by defects in the paper. In endeavouring to overcome these difficulties, the author hit upon the idea of using metallised or "foiled" paper of the same character as that sometimes employed for wrapping up packages of tea, etc. Experiments showed that commercial "tin-foiled paper" as then made was not sufficiently reliable as an electrical conductor for the purpose; indeed, many samples, although having apparently an excellent metallic surface, were found to be almost as devoid of conductivity as paper itself. Microscopic examination revealed that this want of conductivity was chiefly due to the tin being distributed, not as a continuous film over the surface of the paper, but in small isolated patches, the breaks between the contiguous patches being due to small fibres of the paper standing above the average level. Further, it was found that even in those samples which gave fair conductivity in the plain sheet very little creasing of the paper sufficed to destroy the continuity. The matter was, however, considered sufficiently promising to warrant careful investigation, and the difficulties in the way of producing a thoroughly reliable conducting surface on such paper were found to be surmountable.*

For assistance in carrying this part of the work to a successful issue, the author desires to express his indebtedness to Messrs. Olive

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* U.K. Patent 19451, 1900, G. F. Mansbridge.

& Partington, Ltd., of Upper Thames Street, London, who gave the matter considerable technical attention at their works and who were the first to produce foiled paper for electrical purposes on a commercial scale. As soon as supplies of good electrical foiled paper became available the manufacture of condensers on this principle was taken up by the Post Office, and subsequently by various commercial firms, under licence from the patentee.

The process of preparing this foiled paper is fairly well known in the paper-making trade, but as the matter will probably not be so familiar to members of this Institution, a brief description may be of interest.

As is well known, metallic tin may be thrown down from its solution either chemically or electrically in the form of an impalpable powder, and the preparation of the finely divided metal is the first process. The ingot tin—previously granulated or "feathered"—is dissolved in nitrohydrochloric acid, and after all scum and insoluble matter have been removed, the solution is diluted and the tin is carefully precipitated by metallic zinc, or by the action of a weak electric current. For the best results the most minute subdivision of the tin is essential, since only the thinnest layer of metal is desired, and unless this layer is uniform, metal will be wasted or imperfect continuity will result. After precipitation the powder is repeatedly washed to free it from all traces of acid, and is sifted through sieves of the most minute mesh so as to eliminate all large particles of tin or any grit with which it may have become contaminated. A suitable adhesive such as size is added, and the tin mud is then passed to the coating machines. These are provided with mechanical stirrers to prevent the metal settling, and with rotating brushes and spreaders to distribute the metal evenly over the surface of the paper as the latter passes through the machine. In some machines the paper is passed over heated cylinders so as to dry the coated surface quickly, but as this is liable to reduce the efficiency of the adhesive it is preferable that paper for electrical purposes should be dried more slowly—for instance, by exposure to currents of warm air. The dried paper then presents a dull grey appearance, and microscopic examination shows that the surface is covered by a magma of minute crystalline particles forming a layer of appreciable depth. The paper then passes to the burnishing rolls, which consist of heated heavy steel calenders or friction rollers between which the paper is fed. These friction rollers compress the dull magma of tin powder into a coherent thin film having the lustre of the polished metal. During this process any comparatively large crystals of tin or particles of grit which may have escaped untrapped will be driven partly or wholly through the paper, but the effect of this is eliminated by the subsequent electrical treatment, as described later on. The paper is now passed to the slitting machines, where it is trimmed and cut to any desired width.

It is interesting to note that prior to the calendering process referred to, the film of tin powder is non-conducting, the conductivity being produced by the action of the steel burnishing cylinders, which so consolidate the coating as to bring the particles into intimate contact each with its neighbour. Perfect contact between every particle of tin and its immediate neighbours can hardly be expected, but in view of the entire want of conductivity before calendering, it is perhaps surprising that in properly calendered foiled paper, with a fairly heavy coating, the conductivity of the coating may be as much as 50 per cent. of that of a continuous strip of pure tin of equivalent weight. On the foiled paper as usually made for condensers, the quantity of tin averages 25 grains to the square foot, and the conductivity is about 25 per cent. of that of pure tin, the resistance of a strip 1 ft. wide averaging 0·3 ohm per foot run, that is, 0·3 ohm per square foot or per square metre. This density of coating gives a surface of 280 sq. ft. to the pound of tin, or say, 57 sq. metres per kilogramme of tin. The average thickness of the tin film is therefore as nearly as possible 0·0001 of an inch, or say, 0·0025 millimetre. Seeing that the material is semi-transparent, the current-carrying capacity of this film is surprisingly high, the fusing current in air being rather more than 1 ampere per inch of width for the standard coating of 25 grains per square foot; this is assuming that the paper has not been creased. Bending the paper round even a very small radius does not affect the continuity, but if the paper be very closely folded back on itself so as to put the film sharply in tension or compression, a certain amount of disintegration follows, and the fusing current is correspondingly lower. By using a greater density of coating, say, 40 grains per square foot, the effect of creasing is greatly diminished, but there is no necessity for this higher density in condenser work, since the creases in the rolled condenser even at the centre of the roll are not very sharp.

Continuous reels of electrically-conducting foiled paper being available, the manufacture of a condenser is a very rapid and simple operation, since all that is necessary is to roll up together two strips of foiled paper, interleaved with two strips of plain paper, the number of turns being dependent on the capacity required.

The foiled papers may be placed with their metallic sides facing each other, but separated by the two plain papers, in which case the two body papers form the dielectric on the opposite side, or, alternatively, the papers may be arranged so that the dielectric on each side is made up of one body paper and one plain paper. The latter plan is preferable, as it gives a more even distribution of the dielectric strain. Interleaving paper is invariably used for telegraph or telephone condensers, since the insulation otherwise obtainable is but a few megohms. The machine usually employed for the rolling operation accommodates two reels of plain and two reels of foiled paper, and is provided with a set of interchangeable winding mandrels of various diameters. The winding of the strips on to the mandrel is usually done by hand if the number of turns per condenser is small, but in some instances more than a hundred turns have to be wound on, and the mandrel may then be power driven with advantage, but in this case a mechanical counter becomes essential. The placing of the strips in position and the starting must be done by hand, and this also applies to the insertion of the connecting lugs, which should be strips of annealed copper foil, about 0·001 in. thick and $\frac{3}{8}$ or $\frac{1}{2}$ in. wide. These strips are simply slipped into place between the foiled surface and the interleaving paper, and are so light that they readily retain their position; they should make contact with the foiled surface over practically its full width and should protrude about 1 in., so as to serve subsequently as a soldering point for the wire connection. The two lugs should be placed at the middle of the foiled strips rather than at the beginning or end, so as to avoid interposing any appreciable resistance into the condenser circuit. This plan has the additional advantage that thereby the innermost layers, which possibly may have been rather sharply creased, are not called upon to transmit any considerable current on charge or discharge, as would be the case if the lugs were placed at the inner end of the roll.

The necessity for having mandrels of different diameters arises from the fact that variously shaped condensers are demanded; obviously plates of any desired capacity can be made on any one mandrel by merely varying the number of turns. From first principles it would be expected that the capacity would be directly proportional to the area of the electrodes, but in practice it is found that, within limits, plates of high capacity require appreciably less area per microfarad than those of low capacity. This is particularly the case where the thickness of the plate is small in comparison with its length and breadth. There is therefore a saving in material as well as in labour by building the plates in as large units as possible. Further, it is found that plates built with narrow foiled paper require less material per microfarad than those built with wide paper, the treatment and material being otherwise identical throughout. This effect is doubtless due to the wider paper offering greater facilities for trapping the paraffin instead of allowing it to be expressed. The two effects taken together indicate that a condenser in the form of a cube would require less material than one in any other shape. The cube is, however, not the most suitable shape for manufacture, and as the conditions of service are often such as to demand the adoption of thin, flat plates, the usual compromise has resulted. The standard sizes adopted by the Post Office are shown in the specifications included in the Appendix. The capacity most in demand for telephone work is 2 microfarads, and as plates of this size form a convenient manufacturing unit, they are usually taken as the basis on which to frame standard data for manufacturing purposes. Condensers of larger capacity are almost invariably built up by assembling standard units, rather than by direct manufacture in large plates. The usual sizes of paper at present in use are: for interleaving paper, $7\frac{1}{8}$ or 4 in. wide by $\frac{1}{2}$ mil thick, giving about 400 sq. ft. to the pound; for foiled paper, $6\frac{3}{8}$ or $3\frac{1}{2}$ in. wide by $1\frac{1}{4}$ mils thick, giving 100 sq. ft. of conducting surface to the pound, and consisting of 35 per cent. tin and 65 per cent. paper.

At one time an unfoiled margin was left on each side of the foiled strip, but since the introduction of the "breakdown process" subsequently referred to, this has been found unnecessary. The substance of the paper is gauged on a ten-fold thickness by means of the usual screw micrometer, as specially made with large contact surfaces for paper gauging. With 1¼-mil foiled paper and ½-mil interleaving paper, the area required for a 2-microfarad plate is about 12½ sq. ft. for each electrode. The volume of the plate after waxing and pressing is approximately 7½ cub. in., and the weight 7 oz. The insulation between the electrodes, taken at 60° Fahr. with 400 volts after one minute's electrification, usually lies between 1,000 and 2,000 megohms per microfarad.* Any lower insulation than 1,000 megohms per microfarad is an indication of imperfect desiccation, excessive pressure, or faulty material.

It should be noted that the specific insulation (resistivity) of foiled paper is lower than that of plain paper, the difference being due chiefly to the fact that the former is heavily sized. It is, however, only for special purposes that condensers of extremely high insulation are demanded. In such cases, by using the utmost care and material of the very highest quality, it is possible to obtain an insulation of nearly 20,000 megohms per microfarad (400 volts, 60° Fahr., 60 seconds). Such condensers are invariably built up of sheets rather than by the rolling process, since it is necessary to use only perfect sheets, and the rolls of paper cannot readily be examined; under these conditions metallic foil may be used in preference to foiled paper. Three sheets of paper are usually interleaved between consecutive foils. The obvious, but often overlooked, fact may here be commented upon that to increase the number of interleaving papers, while increasing the actual insulation of the plate, does not increase the "megohms per microfarad," since the capacity falls in proportion to the rise of insulation, provided, of course, that there is no abnormal leakage through definite faults.

For certain purposes, such as absorbing the spark across the break of sparking coils, leaky condensers, that is, condensers with specially low insulation, are of advantage, since the high-resistance shunt afforded by the low insulation across the break materially assists in suppressing the primary spark and in thereby lessening the pitting of the contacts. The low insulation necessary may conveniently be obtained by rolling up foiled paper without any interleaving paper, the plate being in other respects treated in the ordinary way. The insulation obtainable will depend partly on the thickness of the foiled paper and partly on the intensity of pressing, but will usually be of the order of a megohm. An important detail in the manufacture of condensers for spark suppression is that there must be no appreciable resistance in the condenser circuit, that is, in the electrodes or thin connections. The insertion of even 1 ohm in series with the condenser of a high-frequency spark coil markedly increases the sparking at the primary contacts.

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* The expression "megohms per microfarad," though incorrect, is so generally employed that the custom has been followed throughout this paper; the phrase should, however, invariably be interpreted as "megohm-microfarads."

The value of the advance made by the introduction of foiled paper for condenser making lies in the fact that in this material the dielectric and the conductors are more correctly proportioned to their work than is possible when solid metal foil is used. Owing, therefore, to what may be called the better design of the foiled-paper condenser, it is correspondingly cheaper, lighter, and smaller. Even with foiled paper, although the quantity of metal per unit area is extremely small, the conductance of the electrodes is in excess of the actual requirements, whilst if solid foil is employed, it is necessary to use fully ten times the weight and volume of metal that would suffice if only the conductance had to be considered. The necessity arises from the fact that metal foil cannot be rolled in continuous lengths to give a greater covering surface than about 90 sq. ft. per pound (about 18½ sq. metres per kilogramme), and even with this thickness the foil is extremely tender and requires delicate handling, as, if made of pure tin, it is only 0·0003 in. thick. The metal foil is in addition expensive, and is by far the most costly item in the construction of a condenser. Further, when metallic foil is used, short circuits are very apt to develop both during manufacture and in subsequent use. The short circuits are due to grit in the foil, or to pinholes or other defects in the interleaving paper, or are consequent upon disruptive discharges caused by the application of a voltage in excess of the dielectric strength.

Now with respect to these short circuits or disruptive discharges, however produced, condensers made of foiled paper have the peculiar advantage of possessing to an almost perfect degree the property which in a pneumatic tyre is called self-sealing, and consequently they are practically proof against short circuit, and can be subjected to much higher voltages than is permissible with those made from metallic foil, any momentary short circuits produced by a disruptive discharge being instantly and automatically sealed. This automatic sealing is brought about in the following way: owing to the extreme thinness of the conducting film the small quantity of heat generated at the point of short circuit by the sudden discharge of the condenser through that point is sufficient to cause the film of metal immediately surrounding the point of breakdown to be fused into minute globules. The segregation of these globules from each other and from the surrounding metallised surfaces effectually isolates the point of breakdown, and the defect is instantaneously sealed up. So rapid, indeed, is this effect, that if a pin is stuck into an insulated charged condenser so as to produce short circuits between the foiled papers, the short circuits seal up without fully discharging the condenser, and a dozen or more of such short circuits may be created one after the other before the condenser becomes fully discharged. Consequent upon the observation of such an effect as this, the author conceived the idea of electrically treating

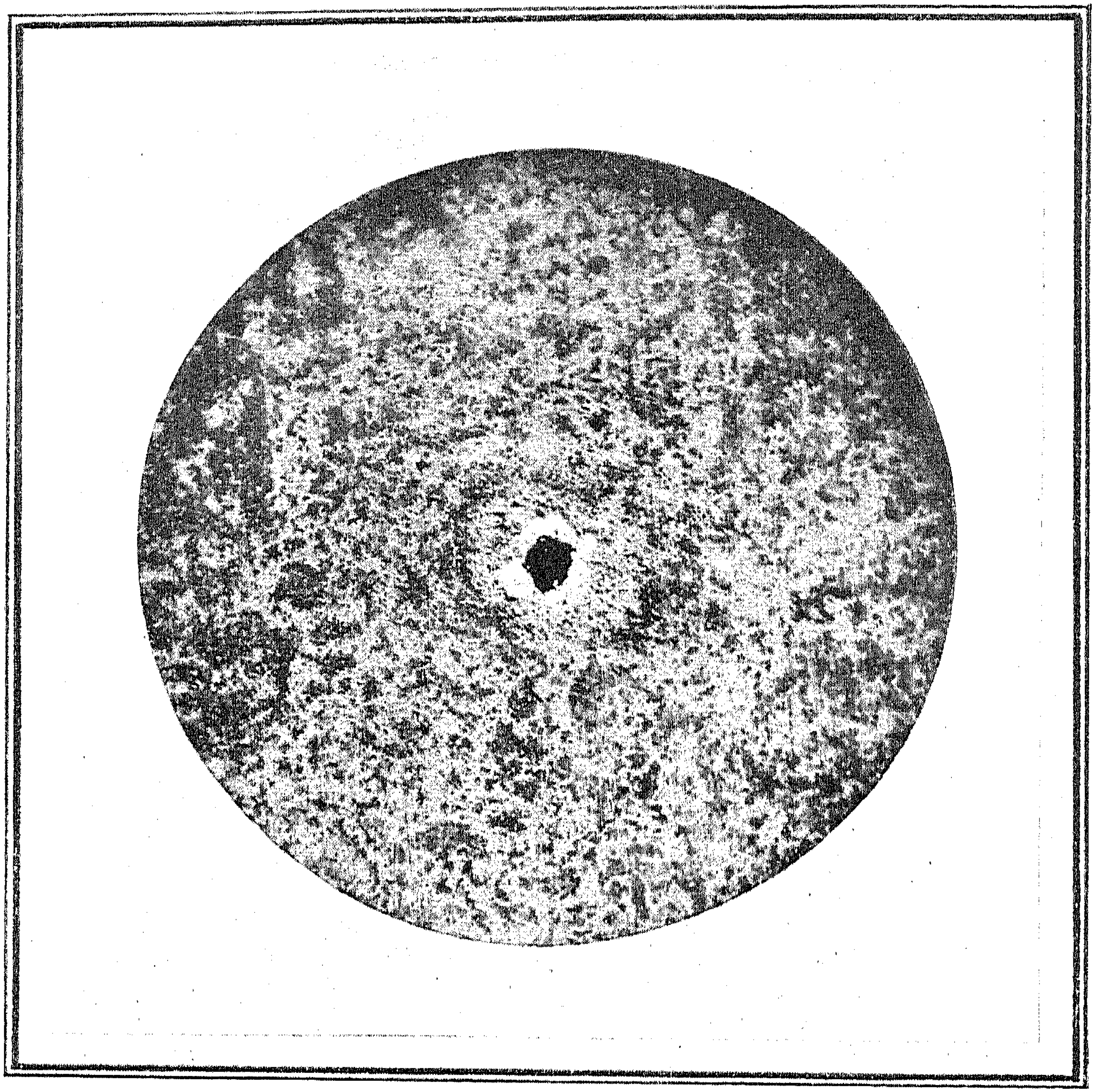

FIG. I.—Micro-photograph of a "Breakdown Point" after Electrical Treatment.

the foiled paper before making it up into condensers in such a way as practically to eliminate all pinholes or defective places by subjecting them momentarily to currents of such strength as to produce a minute non-conducting ring round each defect, thereby isolating it from the surrounding surface.* The apparatus for doing this is of the simplest character. All that is necessary is to pass the paper, foiled side uppermost, over a conducting roller, and to maintain a suitable potential difference between the roller and the foiled surface. When any pinhole or weak place in the paper reaches the roller a short circuit occurs, and the momentary rush of current, concentrated round the defect, produces a bright spark at the defective spot on the foiled surface. As in the case of the finished condenser, the effect of this spark is to isolate the defect by volatilising or fusing the film of metal immediately around it. In this way all the weak places in the dielectric are detected and isolated before the paper is brought into use, and in consequence it is possible to use thinner paper, both foiled and plain, than would otherwise be safe. The process of isolating or removing these faults is quite automatic, and the apparatus once set requires practically no adjustment; all that is necessary in this respect is to see that the current at the moment of short-circuiting is sufficiently strong to fuse the metallic film in the immediate neighbourhood of the defect but is not so strong as to burn the paper. If current from lighting mains is employed a series resistance is necessary to limit the short-circuit current. With 100 volts this resistance should be about 15 ohms, and with 200 volts about 150 ohms. Experience shows that the searching effect of the voltage is increased by connecting a condenser of considerable capacity, say 20 microfarads, across the potential terminals, but a series resistance of about 50 ohms in the condenser circuit is needed to tone down the suddenness of the condenser discharge.

The values given above for voltage, capacity, and resistance are in no sense "critical," and they may be varied considerably without seriously affecting the result; in adjusting the values the best conditions may easily be found if regard be had to the fact that the result desired is the production of a small uncharred hole surrounded by a minute ring of perfectly clean white paper. Fig. 1 is a microphotograph of a typical "breakdown" point after treatment by the aforementioned process. The hole made by the spark is shown as a dark spot, and the ring of paper from which the metal has been completely removed may be seen round the hole, although the want of contrast between the polished metallic surface and the white paper renders the ring somewhat indistinct in the photograph.

As the process of eliminating these defective places in the paper is largely one of breaking down the weak spots, the operation is generally described as the "breakdown process." The voltage used may conveniently be one-half of that with which the finished condenser is finally to be tested, that is, if only single interleaving papers are to be used. If the condensers are to be made for 1,000 volts or thereabouts it is necessary to use double or treble interleaving papers, and in this case the obvious course is to fix the breakdown pressure at a figure which will result in the dielectric of the foiled paper being strained during the breakdown process to an extent rather greater than will be the case when it is finally used. The author's experience is, however, that the majority of defects are shown up and removed by a comparatively low voltage, and that there is little to be gained by using more than 200 volts for this process if the condensers are for telephone or telegraph work. As regards the direction of the current there appears to be little to choose; if anything, the preference may be given to connecting the positive pole to the plain side of the paper, but the device works quite satisfactorily with alternating current. When the breakdown device is driven by an electric motor it is of advantage to have two rollers making contact with the foiled side of the paper at separate points, preferably not less than 2 ft. apart; the current driving the motor may then be led along this strip of foiled paper between the two rollers, so that should there be any break in continuity in the foiled surface the current driving the motor would be broken when the fault passed the first roller, and the stopping of the machine would call attention to the want of continuity. With paper made by reputable makers such breaks rarely occur, but there must always be a risk of this, and as the device is simple and automatic it is worth while to adopt it. Fig. 2 shows the connections of the breakdown rollers as arranged for motor driving.

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* U.K. Patent 22139, 1905, G. F. Mansbridge.

If the apparatus is mechanically driven, a suitable relay may be connected between the second and fourth rollers so that a local circuit is completed and a bell rung whenever there is any break of continuity between the two rollers.

Joints in the paper may have to be made from time to time. These must, of course, be made electrically continuous, and a simple way of effecting this is, after the ends have been joined by lapping and pasting in the ordinary way, to paste on to the foiled surface a 6-in. strip of foiled paper placed face downwards, so that part of the foiled surface of the strip makes contact with one side of the break and part with the other. It is not desirable to paste the whole of the surface of the strip, since the continuity of the film may thereby be destroyed; the usual plan is to paste merely the edges on each side, leaving the middle portion clean. Good flour paste is found to give satisfactory results.

The condenser plates having been wound then pass to the drying oven, and subsequently to the vacuum pans and screw-presses. The desiccation of the plates prior to waxing must be very complete and thorough if the highest insulation is required. Ovens heated by gas, steam, and electricity are in use for this purpose, but the last-named is infinitely preferable. The ease with which the temperature can be controlled, and particularly the facility with which the heat can be kept to its legitimate purpose instead of being dissipated throughout the shop, and the absence of objectionable fumes and of steam joints, which always give trouble sooner or later, are advantages sufficient to place this form of oven easily first. For an oven of about 25 cub. ft. capacity which will accommodate five hundred 2-microfarad plates, a power consumption of 2 k.w. suffices. The length of time necessary to produce thorough desiccation depends upon the temperature of drying, the relative dryness of the air, and the degree of contact between the hot air and the paper. The temperature permissible is limited by the necessity to avoid scorching the paper, since cellulose suffers adverse physical changes if heated much above 212° Fahr. for any considerable time. Consequently the practice at one time was to dry the condensers at a temperature of 212–220° Fahr., but this involved from three to four days' stoving unless the plates were composed of only a very few sheets or layers, and were disposed in such a way that the heat could readily permeate, and the moisture readily leave, the innermost layers. This in commercial work is impracticable, since some condensers of ordinary size have over 100 convolutions, that is, 800 layers of paper in the flat roll, and a great many have to be accommodated in the oven at the same time. In seeking for means to introduce heat into the interior of the condenser, and thereby to expedite the drying process, the author tried the plan of utilising the resistance of the strip of foiled paper to generate heat in the interior of the condenser when a current of suitable strength was passed along it. To this end all that was necessary was temporarily to short-circuit the plate by means of the connecting lugs at the commencement of the

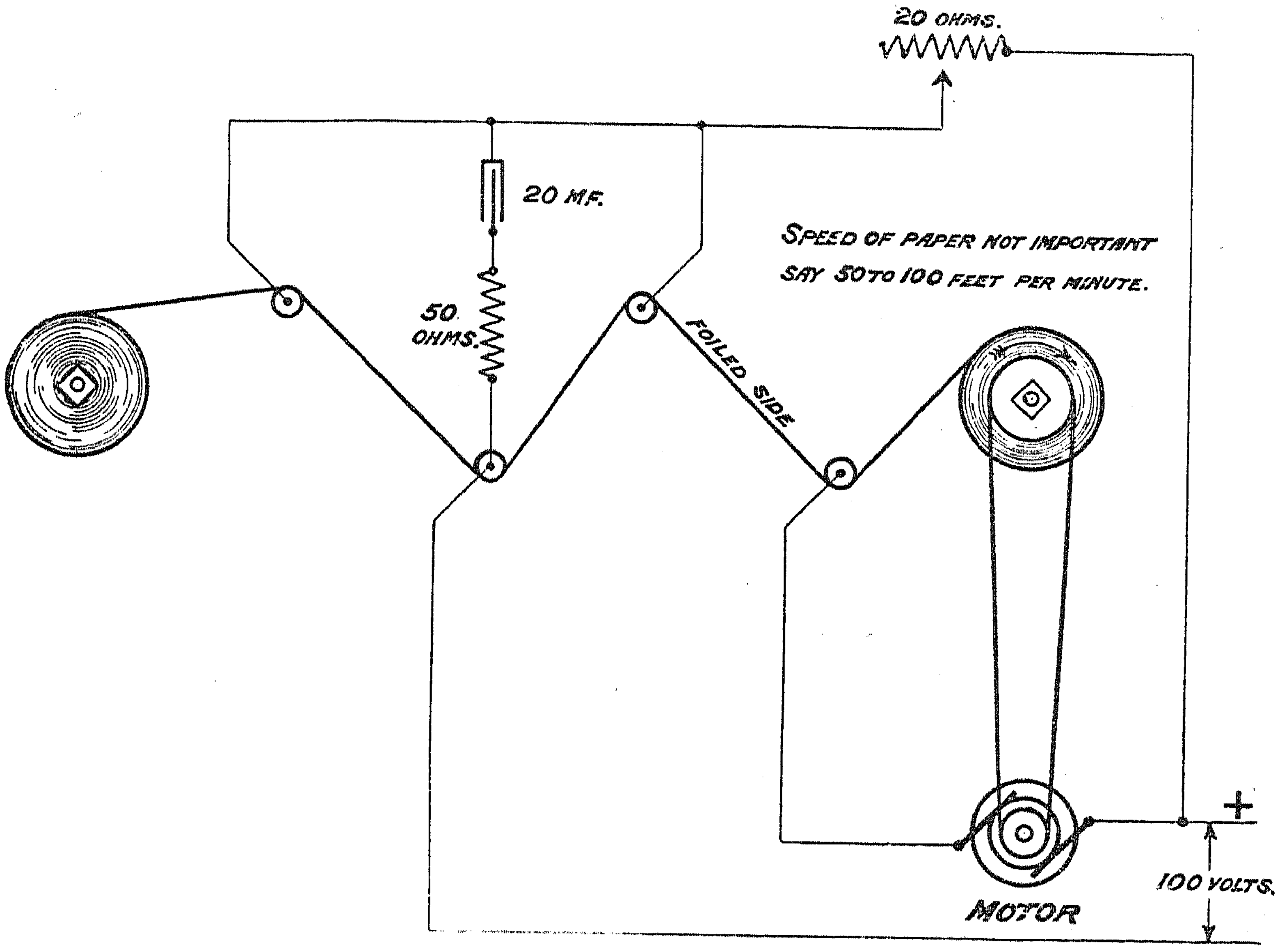

FIG. 2.—Device for treating Tinfoil Paper.

roll, and to pass the current in at another pair of lugs at the end of the roll. It was found in this way, that with an oven temperature of 212° Fahr., and an additional expenditure of 4 watts per 2 microfarad plate, thorough desiccation could be effected in 8 to 12 hours, without any scorching of the paper, although the temperature inside the rolled condenser reached 270° Fahr. Although fairly simple in manipulation, this method did not lend itself very readily to commercial manufacture on the large scale, but it served to point the way to the possibility of using higher temperatures without scorching, and it eventually led to the use of a simple process which has been found most satisfactory and efficient, namely, the vigorous churning of the heated air inside the oven by means of a fan. This rapid circulation results in a great number of particles of heated air being brought into contact with the paper in a given time, and as a result of numerous trials it is found that the use of a fan in this way permits of temperatures as high as 290° or 300° Fahr. being employed without scorching the paper. It will be understood that the fan does not create a circulation of air from outside, but merely churns the hot air in the oven, and although after a time this air becomes more or less moisture-laden, the high temperature enables it to absorb an enormous weight of water before reaching saturation point. By running up the temperature in this way satisfactory desiccation can be obtained in as short a time as 8 hours, and this quick drying is of very great advantage where a large output has to be maintained.

Fig. 3 is a graph of the insulation of various batches of foiled-paper condensers which were subjected to different periods of drying under the conditions indicated above.

One point calling for attention as regards the drying of condensers is the shrinkage in length which takes place with many papers during desiccation. In the case of plain paper newly come from the mill, this may amount to $\frac{1}{2}$ per cent. after 24 hours' drying at 212° Fahr., and there is a further shrinkage on waxing. In the case of foiled paper the shrinkage on drying is much less, and the whole of this occurs prior to waxing. If perfectly fresh and undried interleaving paper is wound up tightly with foiled paper and the compound roll is then dried and waxed, there will be a tendency for the great shrinkage of the interleaving paper to cause the foiled paper to crinkle or crease when pressed. To guard against this, the plain paper should either be matured for a few months in stock, by which time it will have shrunk considerably, or it should be oven-dried for some hours before use.

After being effectively desiccated the plates have to be impregnated with paraffin wax. The function of the paraffin is three-fold :—

1. To increase the inductive capacity of the dielectric.
2. To prevent moisture from again reaching the highly hygroscopic paper.
3. To retain the condenser in the closely compacted form into which it is compressed while the wax is hot.

The inductive capacity of the layers of paper and air which separate the electrodes before the plate is impregnated is approximately 1·2, and on the air being replaced by paraffin this increases to approximately 3·2. Obviously the more thoroughly the air is replaced by the paraffin the greater will be the gain, and to facilitate this it is advantageous to impregnate the condensers *in vacuo*. Hot wax very readily penetrates paper, and it might be thought that soaking for several hours in paraffin at 212° Fahr. would suffice thoroughly to impregnate the paper, but as the result of tests of some batches aggregating a thousand plates it was found that the gain in capacity due to impregnation under vacuum averaed 11 per cent. This means that by using the vacuum process 11 per cent. less material is required for a given capacity, while in addition the condenser produced is more reliable, since every isolated air-bubble entangled in the interior tends to reduce the dielectric strength by causing unequal distribution of strain, and also tends, by

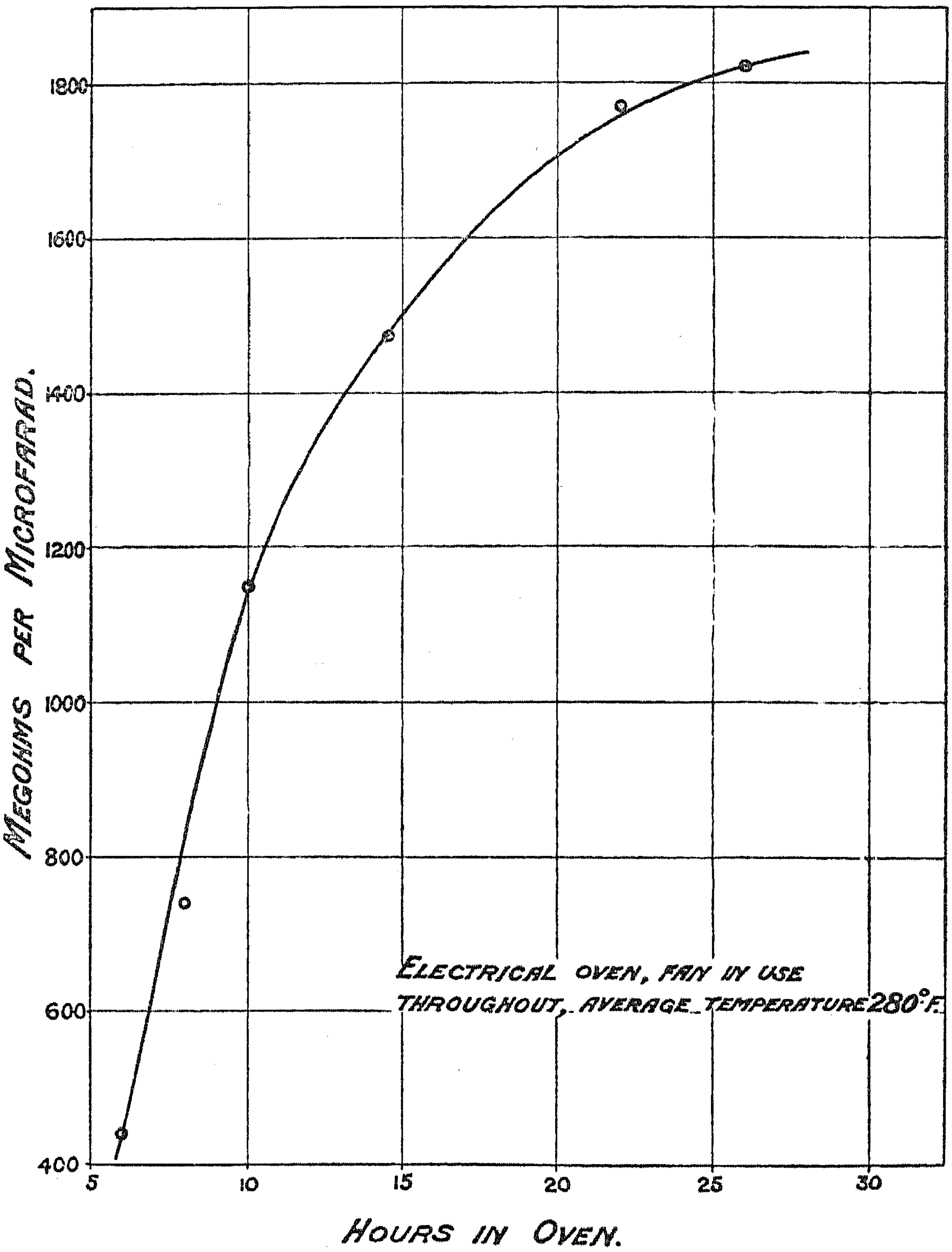

FIG. 3.—Foiled Paper Condensers. Average Insulation (300 Volts, 60 Seconds, 60° Fahr.) after various Periods of Drying.

expansion and contraction, to cause, in time, a drop in capacity by separating the layers, and a drop in insulation by affording an opportunity for moisture to enter the interior of the plate. An obvious way of impregnating *in vacuo* is to exhaust the air from the pan containing the condensers, and then after complete evacuation to run in the hot paraffin; but equally good results can be obtained by simple exhaustion over the wax, that is to say, by plunging the plates into a pan of hot wax, fastening the lid, and then maintaining a vacuum in the upper portion of the pan. The advantage of the latter plan is as follows. In order to facilitate the exhaustion it is necessary to heat the paper; this heat can most conveniently be conveyed into the inside layers of paper by means of the hot wax. If the exhaustion is carried out with the paper dry there is no vehicle to carry the heat into the interior of the condensers, and only radiated heat from the sides of the pan is effective, since the air has been withdrawn; for other reasons also the plan of evacuating over the wax is found to have the balance of advantage. A photograph of a convenient form of vacuum pan is shown on the screen. This pan is gas-heated and will accommodate 150 2-microfarad plates per charge. To prevent deterioration of the paraffin by scorching, the bottom of the pan is made exceptionally thick and several rows of minute gas jets are provided so as to distribute the heat uniformly over the bottom. To facilitate the circulation of the hot wax the plates are not allowed to rest upon the pan itself, but are laid upon a loose metal grid which stands up an inch or so from the bottom of the pan. Two hours impregnation at 212° Fahr. is sufficient if a thoroughly good vacuum is obtained. After full impregnation the vacuum is broken and the condensers are left subjected to atmospheric pressure for ten minutes, and are then removed from the hot wax and at once pressed. No advantage can be traced from the employment of more than atmospheric pressure in the pan after evacuation is complete. The method of pressing and the manipulation at this stage are of considerable importance, and it may therefore be well to describe this operation in detail. In the first place it will be obvious that the greater the pressure the greater, within limits, will be the capacity obtained, and with this object it is the practice in certain factories to employ hydraulic machinery and to compress the plates to the utmost limit. The objections to this course are, however, considerable. First, there is a great tendency to drive the paraffin out of the pores of the paper and so to leave the paper readily penetrable by moisture, unless the plates are at once hermetically sealed. Secondly, the enormous pressure greatly increases the liability to short circuits, and although this is of little importance with foiled-paper condensers owing to the automatic sealing, it is better to avoid it since such breakdowns after the paper has been waxed are always accompanied by a fall in insulation. Thirdly, the excessive pressure results in lowering the insulation to an extent which is out of proportion to the increased capacity. This effect, which is shown graphically in Fig. 4, necessarily follows from the reduction in the proportion of paraffin to paper, since the wax has much the higher specific insulation. A further objection to hydraulic pressing is that for commercial reasons it involves the simultaneous pressing of a vertical pile of plates, and this procedure is to be deprecated since the cooling of such a pile is necessarily slow, and the wax continues to drain out of the inner condensers to such an extent that when cold there is comparatively little left in them. As the result of experience, it can be said that for a condenser which is required to maintain its insulation and capacity for many years it is of first importance that a good body of wax be left in the plate. For this reason the pressing of even two plates one above the other is not permitted at the Post Office factory. The same objections do not, of course, apply to the pressing of a number of plates side by side; indeed, this is the current practice, and it is found to give satisfactory results. With the same object—namely, that of retaining a sufficiency of wax in the plate, the presses are water-cooled both

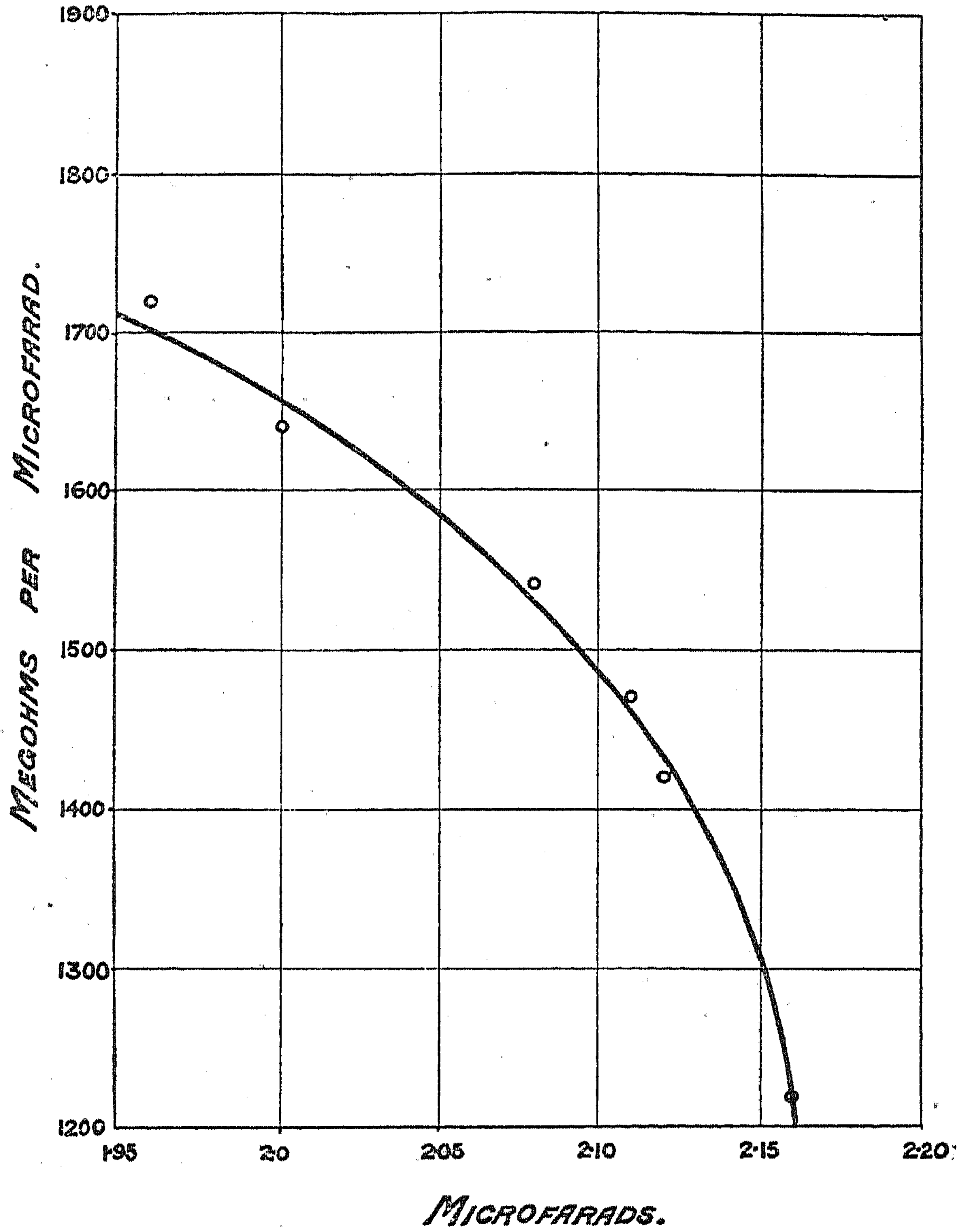

FIG. 4.—Foiled Paper Condensers. Relation between Capacity and Insulation of similar Condensers, subjected to differing Degrees of Mechanical Pressure.

on the top and on the bottom. This water-cooling, in addition to the technical advantage referred to, has also the commercial advantage of increasing the output of the presses, which is of importance now that condenser manufacture is carried out on such a large scale. With cooling water at a temperature not exceeding 60° Fahr. five minutes' cooling in the press suffices for a condenser $\frac{1}{4}$ in. thick; for plates of greater thickness a correspondingly longer time is necessary. The presses are of the screw type, and the question naturally arises as to why this form is adopted in preference to the apparently more scientific method of a lever and dead weights. Contrary to what might be expected, experience shows that more uniform results can be obtained with screw-presses than with levers and dead weights, and the latter form has consequently been altogether abandoned at the Post Office factory. Even the use of gauge-blocks for the screw-presses, by means of which the condensers are pressed to a certain definite thickness, seems to give less uniform results than can be obtained by a careful workman with a little practice, without any guide other than the "feel" of the press, and an occasional capacity test of the plates as they come from the presses. One objection to the gauge-blocks is that they do not allow for the small commercial variations which are constantly met with in condenser manufacture, and another is that they tend to reduce the operation of pressing, which is one that really requires some little skill and care, to the mere manipulation of a machine.

As soon as the plates are fairly cold they should be placed aside to settle down in temperature before being tested, and in the meantime they should be protected from atmospheric moisture. Paraffin, contrary to the opinion of the layman, is markedly hygroscopic, and it is important that the outer layer of wax should not be allowed to absorb moisture before the condenser is hermetically sealed; otherwise the insulation will steadily fall, as the moisture diffuses throughout the mass.

In addition to or in substitution of paraffin, various waxes and mixtures have from time to time been proposed for condenser work. Beeswax, resin, shellac, ceresine, stearine, lead stearate, etc., have all been suggested, and for each some special advantage has been claimed in the way of higher inductive capacity, greater dielectric strength, or less affinity for moisture as compared with paraffin. The author has, however, been unable to find that any one of these substitutes possesses the all-round advantages of good paraffin; this material, plain and unadulterated, is therefore recommended save for special cases where a peculiar property of one or other of the substitutes may justify its use to meet the peculiar conditions. For condenser work a high quality of wax is necessary, but this does not necessarily imply a high price or a high melting-point. For use in tropical countries paraffin of a specially high melting-point is desirable, but for use in the temperate zones wax with a melting-point of about 130° Fahr. answers most requirements. The melting-point or, more correctly, the "setting"-point, may be determined in a very simple way, although various methods of a more elaborate character find favour in some chemical laboratories. The plan adopted by the author is to insert a calibrated thermometer with a small bulb into a vessel of hot wax, and as the wax cools to observe the fall of temperature with respect to time. If the thermometer and the quantity of wax are suitably chosen there will be a well-defined period during which the temperature becomes stationary; this temperature represents the setting-point. The observation can be repeated by different unskilled observers with identical results, provided that the local conditions are approximately the same for each observation. Some typical curves showing the result of this method are reproduced in Fig. 5. A convenient quantity of paraffin is about 2 oz. contained in a test tube or beaker 1½ in. in diameter; the thermometer generally used has a bulb of ¼ in. diameter by ¾ in. long. If a thermometer with a very large bulb is used the effect may be partially masked, since the quantity of latent heat given out by the paraffin on solidifying is not great, but even under these conditions the setting-point may be estimated very closely.

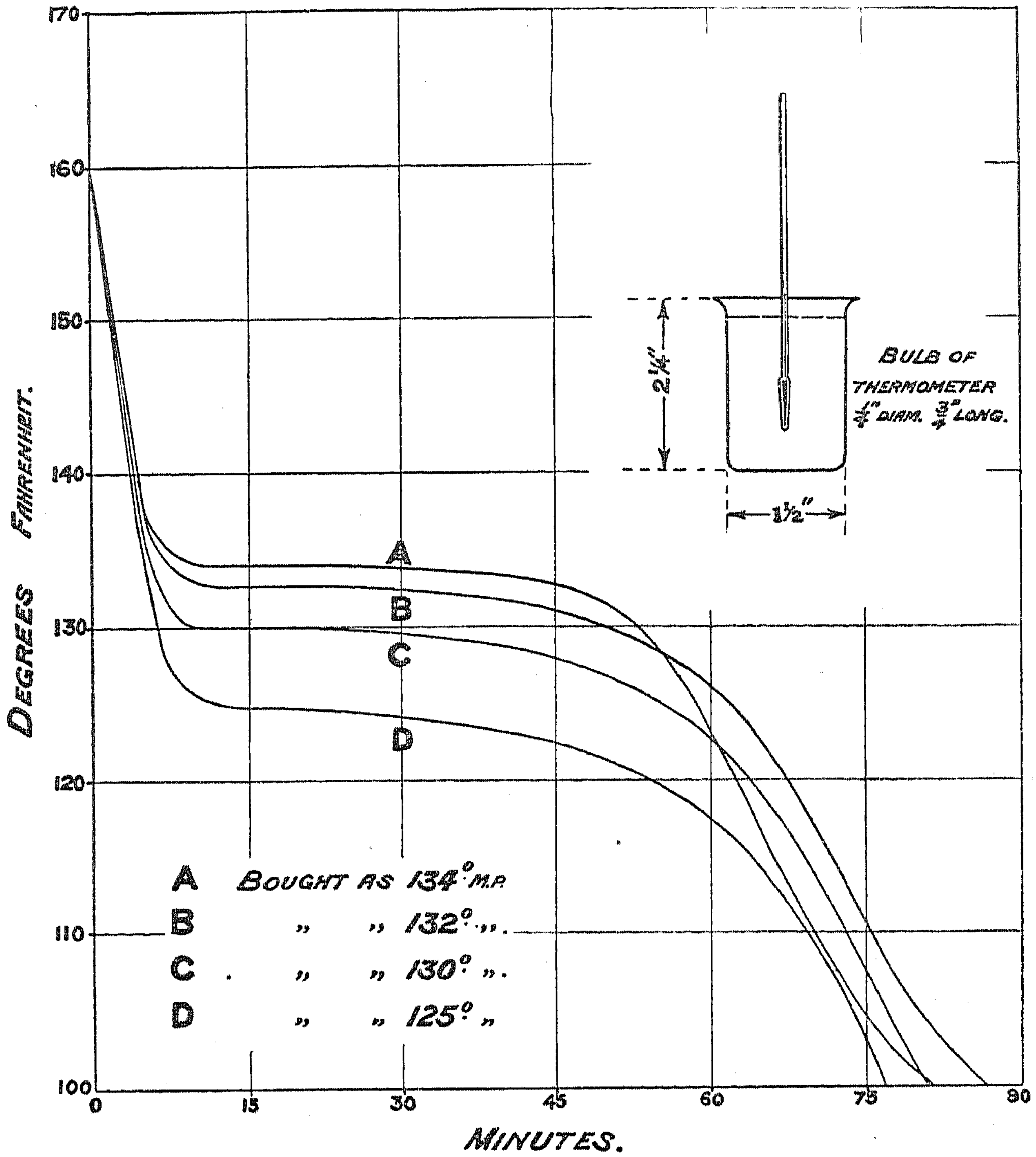

FIG. 5.—Cooling Curves for Paraffin Wax.

For condenser work the wax cannot be considered satisfactory unless it is chemically neutral and free from unsaturated hydrocarbons. Its suitability in this respect can readily be ascertained by the usual chemical tests.

Before being run into the vacuum pan the wax should be strained through sieves of the finest mesh (a few thicknesses of muslin will answer very well) to remove mechanical impurities.

In all stages of condenser manufacture handling by the workmen should be restricted to a minimum, and no operative who is inclined to perspire freely should on any account be permitted to handle the plates prior to boxing. Paraffin readily absorbs the moisture and salts of the body, and a condenser plate, once contaminated in this way, will have a short life so far as insulation is concerned. From this point of view the ideal method of manufacture is to place the dried plates in metallic cases, to plunge the whole into the hot wax, then to exhaust the air, and finally to take out the condenser complete in its case so that the plate after impregnation suffers no handling whatever. The objections to this plan are that there is so little control over the capacity, and that there is such great waste of material, since the pressure which can be brought to bear is so small; the method can, however, be recommended where long life is of more importance than first cost.

In default of reaching the ideal, the best that can be done commercially is to handle the plates as little as possible and to seal them hermetically in metal cases as soon as possible after manufacture, and this is the course adopted at the Post Office factory. Reference has already been made to the question of dielectric strength. As is well known, this, with paraffined paper, is apt to be a very variable quantity, particularly when—as with most commercial condensers—the electrodes are separated by only two thicknesses of paper, since a weak spot in one of them so largely reduces the resistance to disruptive discharge.

As a rough approximation, it may be said that with ordinary paraffined paper at 60° Fahr. the breakdown-point is approached when the pressure reaches the equivalent of 150,000 volts per centimetre. With foiled paper, however, the result of the automatic sealing is practically to double the effective dielectric strength.

Fig. 6 shows graphically the results obtained on subjecting an ordinary telephone condenser, made from foiled paper, to steadily increased pressure. As the voltage rose above the normal point of dielectric strength the paper broke down, possibly at several places, but each short circuit sealed up as fast as it was formed, and not until the pressure reached 1,200 volts was the condenser rendered useless.

For telegraph condensers, which are generally required to be adjustable, an outer wooden case carrying a peg-switch is provided; the internal construction is as follows. Separate condensers of suitable capacity are selected, and after a preliminary test are assembled between a pair of sheet-iron plates, which are then bolted together. The object of these clamping plates is two-fold; first, to build up the separate condensers into a substantial mechanical structure; and secondly, to keep upon them a certain degree of pressure so as to counteract the natural tendency towards a drop in capacity. The batch of plates so assembled is built up into a solid mass with plastic paraffin, and is then hermetically sealed in a tinned-iron case, the opening where the wires are brought out being sealed with a non-contracting mixture of gutta-percha, resin, stearine pitch, and Stockholm tar.*

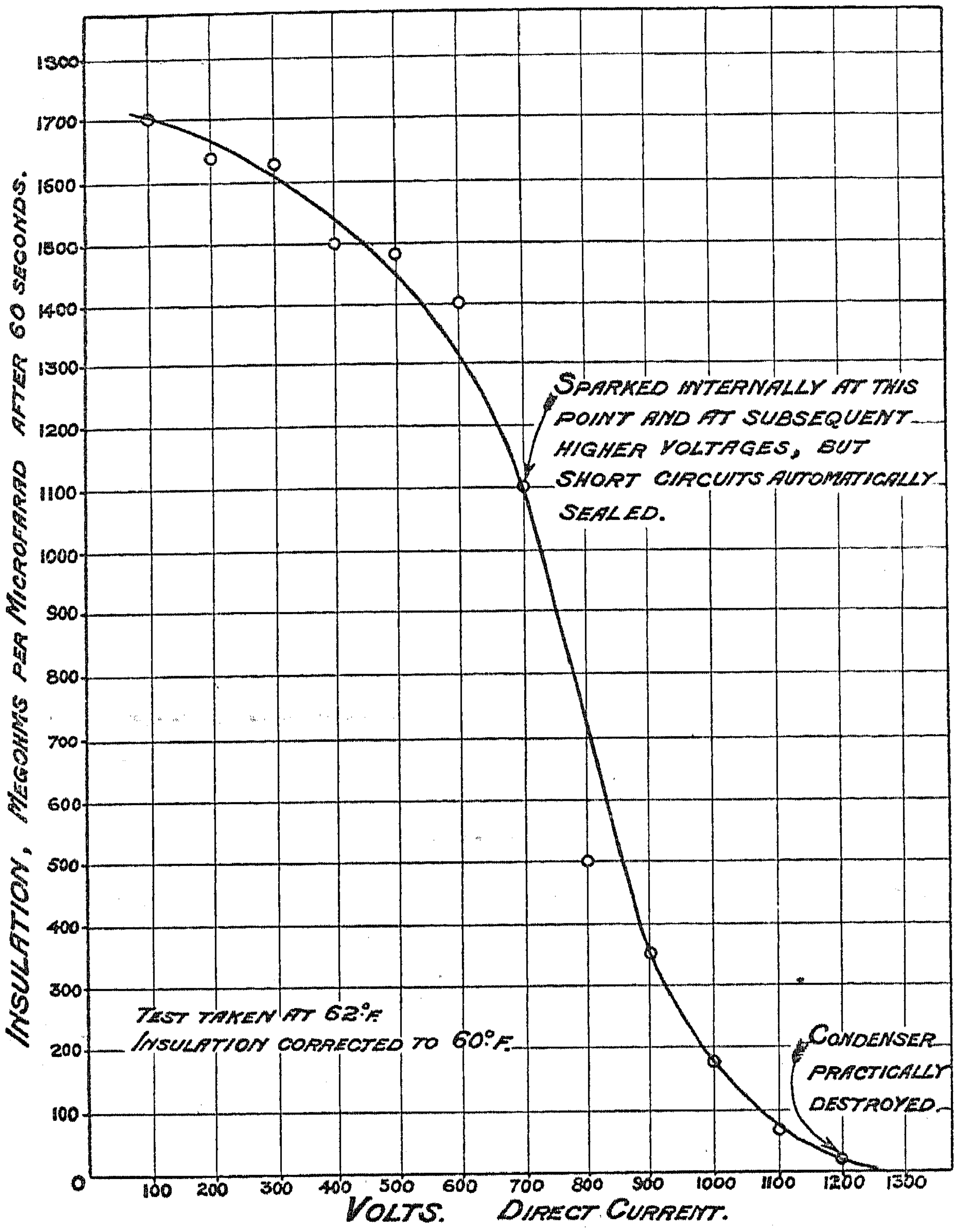

FIG. 6.—Foiled Paper Condensers. Curve showing Relation between Testing Voltage and Observed Insulation.

This compound does not flow at high temperatures, does not get brittle when frozen, adheres firmly to metal surfaces, and contracts

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* The mixture consists of :—

Gutta-percha scrap	20 parts
Resin	14 „
Stearine pitch	6 „
Stockholm tar	14 „

Commercial stearine pitch varies considerably in hardness, and if the mixture so made proves too hard it may be tempered by the addition of a little boiled linseed oil.

very little on cooling. The same mixture is used for sealing the top of the tin cases of telephone condensers, the metal cap which is subsequently soldered in position being merely a mechanical protection.

For telephone work nothing more is necessary than a hermetically sealed metal case, since the condenser is usually covered up and protected by the telephone apparatus. On the Continent papier-mâché cases have been adopted to some extent, but their use cannot be recommended, since papier-mâché readily absorbs moisture, and in consequence the insulation of a condenser contained in a case of such material cannot be relied upon for any length of time. Such cases are cheaper to make than metal ones, and they obviate any risk of contact between two circuits *viâ* the cases of two contiguous condensers, each of which has developed contact with one of the contained electrodes, but inasmuch as satisfactory and lasting insulation between the electrodes and the case is obtainable with ordinary care there would seem to be no sufficient reason for the employment of such an untrustworthy material as papier-mâché.

In speaking of the insulation resistance of a condenser it is necessary to be most precise as to exactly what is meant. The insulation is usually expressed either in terms of the percentage loss of charge after the charged condenser has been insulated for a certain time or as so many megohms per microfarad. The "percentage-loss-of-charge" method is used chiefly for standards and for submarine cable condensers; for ordinary telegraph and telephone condensers the insulation is more often reckoned as "megohms-per-microfarad." Neither expression is a precise specification of the insulation value unless certain datum lines are assumed or stated. The first of these necessary data is the temperature at which the test is taken, the second is the value of the voltage applied, and the third is the time which is allowed to elapse between the first application of the voltage and the moment at which the leakage is measured. For the loss-of-charge method the periods of charge and of insulation have to be stipulated. The latter period is commonly taken as 1 minute, but the period of charge is not so well standardised, 15 seconds being taken by some observers and 60 seconds by others. The pressure often employed for this test is 100 volts. Of the scanty literature on this subject the most noteworthy seems to be that contained in an article * by Messrs. Dearlove and Sayers, who have given the results of some interesting experiments made by them on tinfoil and paper condensers as made for submarine telegraph work.

With respect to temperature, 60° Fahr. is in this country the standard generally accepted for tests made by both methods.

The voltage adopted for the "direct deflection" or megohms-per-microfarad method varies according to the nature of the duty demanded of the condenser. The period of application of the pressure in this case is usually 2 minutes; the leakage is measured at the 60th second after the moment of application, and the insulation is calculated on the basis of that moment's reading. During the whole period of the test the leakage should steadily decrease; and as a measure of this absorption or "electrification," it is usual to take the difference between the readings at the end of the 60th and the 120th second respectively, and to express this difference as a percentage of the reading at the 60th second. With a good condenser

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* *Electrical Engineering*, March 21, 1907, "Relative Dielectric Resistance at various Temperatures of Paraffined Paper Condensers."

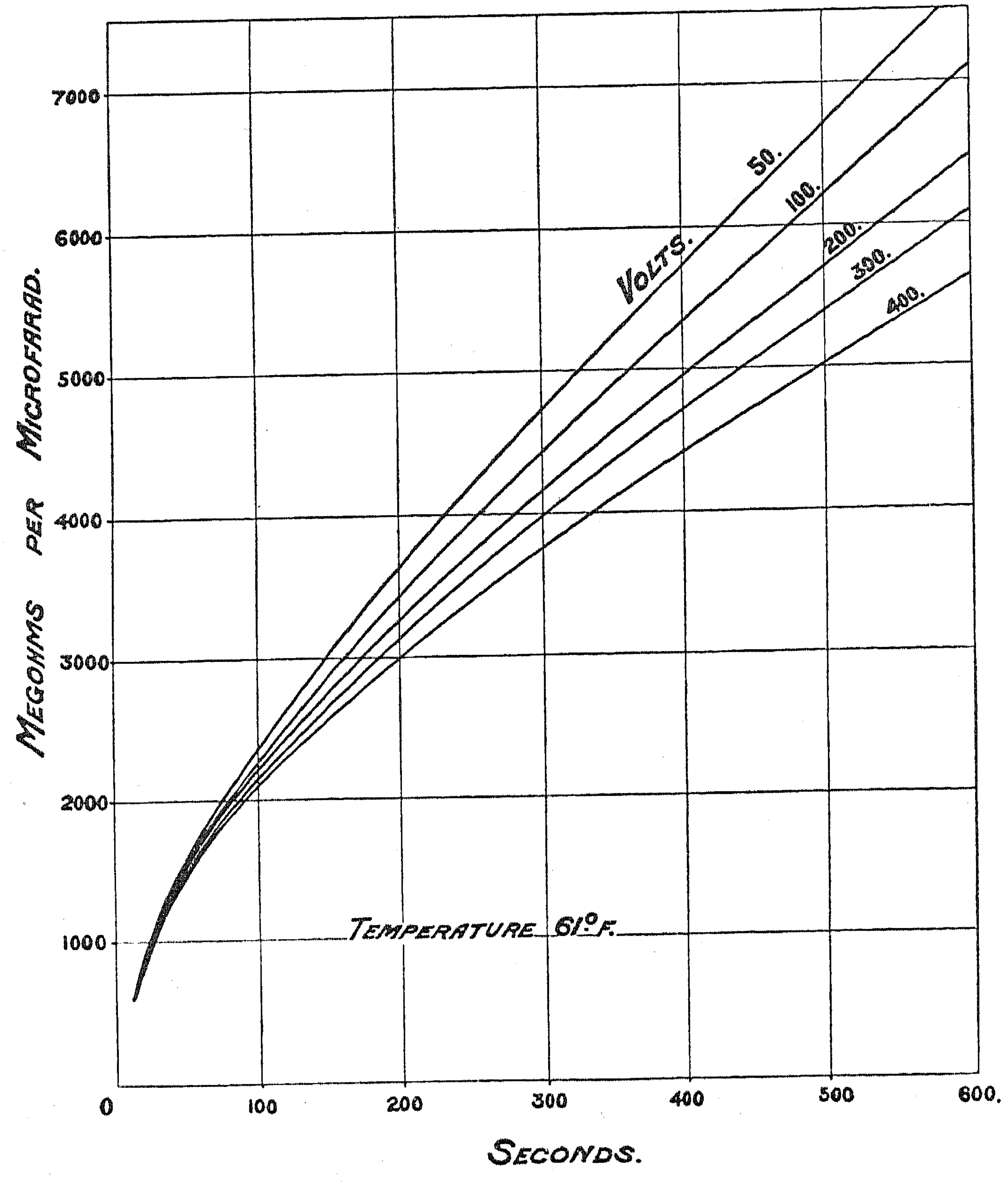

FIG. 7.—Foiled Paper Condensers. Insulation and Electrification with various Voltages.

this percentage will usually fall between 25 and 35 if the test is taken at 60° Fahr. The degree of electrification falls markedly with a rise in temperature. The behaviour of a condenser in respect to electrification is an important indication of its quality, as incipient defects give the first indication of their existence by producing unsteady or "negative" electrification. Fig. 7 shows typical insulation and electrification curves of foiled-paper condensers when tested with various voltages. The relation between time and insulation, and also between voltage and insulation, is clearly shown by these curves, and it needs only a glance at them to see how necessary it is closely to specify the precise data of any test. Fig. 8 shows similarly the variation of insulation with constant voltage and varying temperature, the tests being taken after 1 minute's application of the voltage, the temperature in each case being maintained for a period long enough to allow the condenser thoroughly to take up the new temperature. As may be deduced from the curve, the correcting coefficient for foiled-paper condensers is as nearly as possible 3·50 per cent. per degree Fahr. or $Y_{60} = Y_t\,1{\cdot}035^{t-60}$, where Y_t and Y_{60} are respectively the observed insulation resistance at t° Fahr. and the corrected insulation resistance at the standard temperature of 60° Fahr. This assumes that the insulation is measured after 60 seconds' application of a pressure of several hundred volts. It is not suggested that this formula has an accuracy which is comparable with that of a copper-resistance temperature

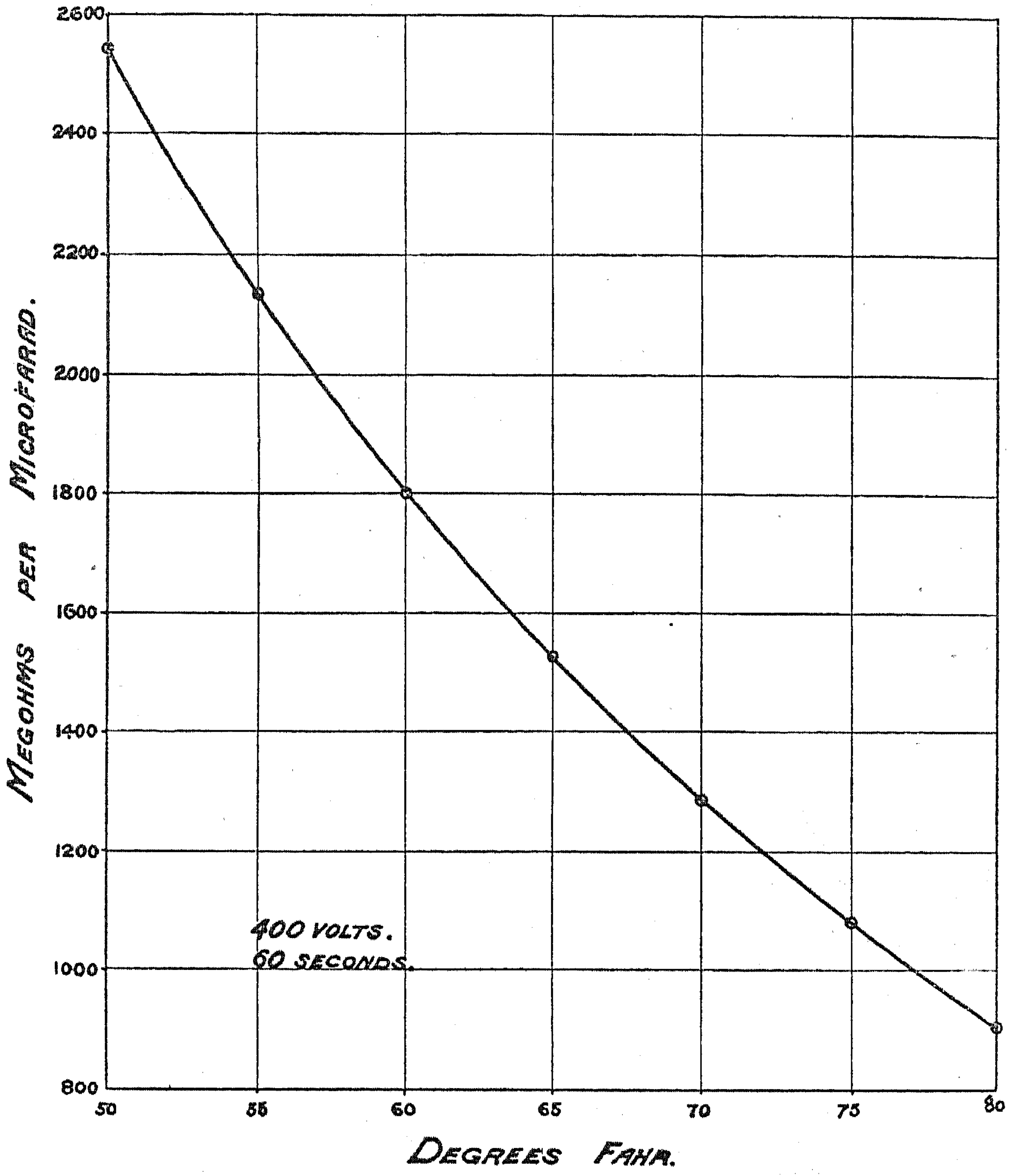

FIG. 8.—Foiled Paper Condensers. Variation of Insulation with Temperature. (Curve plotted from calculated figures.)

coefficient, since the difficulties of measurement are so much greater in the former case, but it is thought that the formula will be found generally to give, over a considerable range of temperature on both sides of 60° Fahr., results sufficiently accurate for commercial purposes.

From general considerations one may anticipate the existence of a relation such as—

$$\Omega \propto \frac{s}{v\,t}$$

where—

Ω = megohms per microfarad.
s = seconds after application of voltage.
t = temperature in degrees Fahr.
v = applied voltage.

Analysis of a number of insulation and electrification curves shows that the relation may be expressed in a simple numerical form, and for foiled-paper condensers the following approximate empirical formula is obtained :—

$$\Omega = 400\,\frac{s^{\cdot 5}}{v^{\cdot 1} \times 1{\cdot}035^{\,t-60}}.$$

For metallic-foil condensers the expression becomes—

$$\Omega = 4{,}000\,\frac{s^{\cdot 5}}{v^{\cdot 1} \times 1{\cdot}035^{\,t-60}}.$$

These empirical formulæ are, of course, only applicable to thoroughly desiccated condensers properly constructed of good material.

A special development of the paper condenser is the "inductive-resistance" form introduced by Dr. Alexander Muirhead for the balancing of long submarine cables. The onerous conditions of duplex working on a long cable call for an artificial line whose electrical constants in all respects approximate closely to those of the real cable. The difficulty in constructing such artificial cables lies in the fact that the constants to be matched are so many; the artificial line must match the real line in resistance and capacity, both in the aggregate and as regards distribution, and at the same time the insulation resistance and electrification must be similar in the two lines. These conditions are closely met by the Muirhead grid type of condenser. This, as is well known, differs only from the tinfoil condenser in that one set of electrodes consists of plain sheets bunched together, while the other set consists of sheets of foil cut into the form of a grid. The strips forming the grid are joined in series and serve as a resistance. The width of the strips may be chosen so as to give within a considerable range any desired ratio between resistance and capacity. The insulation and electrification constants are not so easily matched with accuracy, but fortunately the insulation and electrification of high-class condensers made from thoroughly desiccated paper impregnated with paraffin are of the same order as those of a gutta-percha submarine cable, and an exact match of these constants is not essential. To adjust the capacity and resistance of such an artificial line to a definite value at standard temperature is not difficult, since, for commercial reasons, such condensers are invariably made up from a number of separate plates, and although each of these may be expected to have some variation from the precise figure aimed at, yet by combining high and low plates together the aggregate may be made to agree very closely with the desired figure, and the final adjustment may then be made as with a resistance coil.

The question of maintaining the conductor resistance of such a condenser constant under varying temperatures is a more difficult problem, and is one which, so far as the author is aware, has not been successfully solved; the usual method is to get round the difficulty rather than over it by choosing a situation for the artificial cable where the temperature variations are reduced to a minimum.

The manufacture of such artificial cables is very expensive, owing to the difficulty in handling the thin grid of tinfoil; this may, however, be overcome by the use of foiled paper, since owing to the thinness of the conducting film the strips are much wider than if made of metal, and they are consequently more easily handled. In illustration of this it may be said that artificial cables of very high $\frac{\text{resistance}}{\text{capacity}}$ ratio have been constructed of foiled-paper strip without difficulty. For example, some have been made to match 20-lb. conductor paper-insulated telephone cable, which has a resistance of 44 ohms per mile and a distributed capacity of 0·054 microfarad per mile. Such a proportion with solid metal strip would offer great manufacturing difficulty, particularly as for artificial telephone cables it is necessary that both electrodes be of the strip form; for submarine cables with single conductors the plates are alternately strip and sheet. It should, however, be observed that the insulation obtainable from metallic strip and plain paper is higher than is obtainable from ordinary foiled paper, but by specially preparing the foiled paper this difficulty could probably be overcome.

The workshop apparatus required for testing condensers during and after manufacture depends, to a certain extent, upon the conditions of service. Assuming that the condensers are required to comply with the requirements of the Post Office Specification, the most satisfactory testing set will be found to be a good strained-suspension reflecting galvanometer, carefully calibrated for proportional throws and deflections, together with the usual universal shunt-box, short circuit, and reversing keys, and a primary or secondary battery giving at least 400 volts. Dry cells of modern types and of not too small capacity give satisfactory service for two years or more, but care must be taken to insulate them satisfactorily. The galvanometer and other testing instruments must be carefully "guard-wired," otherwise the tests will be more or less vitiated by leakage. No difficulty has been found in training ordinary workmen to use reflecting galvanometers intelligently and without damage. The strained suspension is of great value in overcoming difficulties due to vibration of the building.

The specification of the National Telephone Company provides for tests of a less simple character. These tests involve the use of sinusoidal alternating currents of speaking and ringing frequencies, and require apparatus of special construction.

By the courtesy of the National Telephone Company, Ltd., the author is able to quote in the Appendix the technical details of this specification.

IV. *Electrolytic Cells.*—These have not been received with much favour in this country, but they were at one time used to a considerable extent in Germany for common battery telephone work. They have, however, been almost entirely discarded in favour of paraffined-paper condensers. The only advantage which these "polarisation cells" possess over condensers is with respect to size, a cell, or a set of cells, capable of stemming back a direct current of 25 volts having a volume of only about 5 cub. in. On the other hand, the cost of such a set of cells is from three to four times that of a condenser of equal effectiveness. The cells used appear to be of three classes, viz.: "Acid cells," consisting of two small electrodes of platinum dipping into an acid solution; "sodium cells" (natronzellen), in which the electrolyte is a solution of a sodium salt; and aluminium cells, in which the electrodes consist of aluminium, and the electrolyte is some kind of basic solution. The acid cells have a damming effect of about 1·8 volt each, the sodium cells about 2·7 volts, and the aluminium cells as much as 30 or more volts. It is probable that the polarisation cell would never have been developed as a practical device if the modern condenser had been available at a reasonable price in the early stages of telephone development. The disadvantage of the polarisation cell is that it is more or less leaky, both electrically and mechanically. The permanent polarisation current passing through each cell is small, but on a system of many thousand subscribers the aggregate leakage becomes considerable. The mechanical difficulty is, however, the more serious one. If the cells are hermetically sealed they are liable to burst owing to the gradual accumulation of gas, which has been known to cause pressures up to 20 atmospheres. To avoid this difficulty some forms are provided with a simple release valve. This is particularly necessary with aluminium cells, as these are of larger size and evolve a greater quantity of gas. It is, however, almost impracticable to prevent some leakage of the solution, and in all the circumstances it is not surprising that the chemical cell has been ousted by the static condenser.

APPENDIX.

POST OFFICE SPECIFICATION FOR CONDENSERS, WOODEN CASED, FOR TELEGRAPH PURPOSES.

The plates to be secured between substantial iron clamps and to be boxed up solid and air-tight with an approved insulating compound, the clamp being secured to the side of the case by means of suitable lugs and screws.

The capacity of each section to be not more than 5 per cent. higher or lower than the nominal value in the case of plates of 1 microfarad and above, and not more than 10 per cent. higher or lower in the case of capacities of less than 1 microfarad, and, in the case of signalling condensers, the difference between the two halves of the condenser to be not more than 0·25 microfarad.

The capacity of each section to be measured by taking the instantaneous discharge after the section has been charged for a period of 10 seconds with an electromotive force of 30 volts.

Each condenser will be tested for insulation and electrification, but these tests will be taken on the condenser as a whole and not on the separate sections, and the tests will be taken with an E.M.F. of 400 volts as follows : The condenser being at a temperature of approximately 60° Fahr., apply the battery for a period of two minutes. The deflection shown after one minute must indicate such an insulation resistance in megohms that when multiplied by the capacity in microfarads the product shall be not less than 1,000. The deflection shall steadily decrease during the second minute, and the difference between the readings at the beginning and end of the second minute shall be not less than 20 per cent. of the first minute reading for 1 microfarad and the larger sized condensers, and 10 per cent. of the first minute reading for condensers less than 1 microfarad, but including 0·5 + 0·5.

The case to be of best well-seasoned Spanish mahogany and to be thoroughly French polished.

POST OFFICE SPECIFICATION FOR CONDENSERS, METAL CASED, FOR TELEPHONE PURPOSES.

The overall length, width, and thickness of the complete condenser, including the outside soldering tags, not to exceed the following dimensions, viz. :—

For condensers	0·5 mfd. ...	$4\frac{3}{4}$ in. × $2\frac{5}{8}$ in. × $\frac{5}{16}$ in.
”	1·0 ” ...	$4\frac{3}{4}$ in. × $4\frac{3}{4}$ in. × $\frac{5}{16}$ in.
”	2·0 ” ...	$4\frac{3}{4}$ in. × $4\frac{3}{4}$ in. × $\frac{9}{16}$ in.
”	2·0 ” ...	(square) $4\frac{3}{4}$ in. × $1\frac{5}{8}$ in. × $1\frac{5}{8}$ in.
”	4·0 ” ...	$4\frac{3}{4}$ in. × $4\frac{3}{4}$ in. × $1\frac{1}{8}$ in.
”	10·0 ” ...	$4\frac{3}{4}$ in. × $4\frac{3}{4}$ in. × $2\frac{11}{16}$ in.

The maximum total weight allowed for each type of condenser, complete with case, is as follows :—

0·5 mfd.		4 oz.
1·0 ,,		8 oz.
2·0 ,,		12 oz.
2·0 ,,	(square)	10 oz.
4·0 ,,		1 lb. 4 oz.
10·0 ,,		2 lbs. 14 oz.

The letters "G.P.O.," the manufacturer's approved code letter, the year of manufacture, and the nominal capacity of the condenser, to be plainly stamped on the metal case as on pattern. The stamping to be done before the condenser is inserted in the case. The actual capacity to be not more than 10 per cent. higher or lower than the marked value.

The capacity to be measured by taking the instantaneous discharge after the condenser has been charged for a period of 10 seconds with an E.M.F. of 30 volts.

Each condenser will be tested for insulation and electrification, but these tests will be taken on the condenser as a whole after fitting in the case and not on separate sections. The tests will be taken with an E.M.F. of 300 volts as follows : The condenser being at a temperature of approximately 60° Fahr., apply the battery for a period of two minutes. The deflection shown after one minute must indicate such an insulation resistance in megohms that when multiplied by the capacity in microfarads the product shall be not less than 300. The deflection shall steadily decrease during the second minute, and the difference between the readings at the beginning and the end of the second minute shall be not less than 20 per cent. of the first minute reading.

The insulation resistance between either of the outside soldering tags and the metal case to be not less than 300 megohms.

The condenser plates to be tightly fitted in the metal case and the top to be hermetically sealed before the metal top is put on. The sealing composition must not be brittle or so soft that it will flow at a temperature of 75° Fahr., and it must adhere firmly to the tinned iron case.

The ebonite strip carrying the tags to be securely riveted to the metal cap, and the latter to fit well and to be firmly soldered to the body of the case at both ends.

The condensers to be fully equal to pattern as regards workmanship and finish.

The case to be stove-enamelled with a finish equal to that of the pattern. The enamel to be hard but non-chipping.

National Telephone Company's Specification for Condensers (Technical Details only).

1. The capacity to be not less than 1·8 nor more than 2·2 microfarads when tested with direct current at 4 to 5 volts, and with an alter-

nating current (sinusoidal wave) at 4 to 5 volts and 800 periods per second.

2. The insulation resistance to be not less than 100 megohms between the two plates and between the plates and the case when tested with an E.M.F. of 100 to 200 volts.

3. The condensers to withstand an E.M.F. of 400 volts maximum (not R.M.S. value), alternating at 20 to 25 ∿ per second applied at the terminals for a period of half a minute.

FOILED PAPER CONDENSERS.

TEMPERATURE COEFFICIENTS FOR CORRECTING INSULATION RESISTANCE TO STANDARD TEMPERATURE (60° FAHR.).

(400 Volts, 60 Seconds.)

Testing Temperature. Deg. Fahr.	To Correct to 60°, Multiply by	Testing Temperature. Deg. Fahr.	To Correct to 60°, Multiply by
50	0·710	71	1·457
51	0·734	72	1·508
52	0·759	73	1·561
53	0·785	74	1·616
54	0·812	75	1·673
55	0·840	76	1·732
56	0·870	77	1·793
57	0·901	78	1·855
58	0·933	79	1·919
59	0·966	80	1·986
60	1·000	81	2·055
61	1·035	82	2·127
62	1·071	83	2·202
63	1·109	84	2·279
64	1·148	85	2·358
65	1·188	86	2·440
66	1·229	87	2·525
67	1·272	88	2·613
68	1·316	89	2·704
69	1·361	90	2·799
70	1·408		

DISCUSSION.

Sir John Gavey.

Sir JOHN GAVEY: I should like to make one brief remark in reference to the introduction of the rolled method at Mount Pleasant. This method was not of my design, as might be gathered from the paper. I owe it to a hint given me by my good friends the Western Electric Company, at New York and Chicago. The way in which Mr. Mansbridge moved onwards from that in use in America to that

Sir John Gavey.

designed by him, known as the foil-paper method, is very interesting, and the manner in which he overcame the difficulties of obtaining a well-conducting foil paper almost resembles a stroke of genius. The fact also that this new method involved a self-sealing condition which eliminated accidental faults is one of very great value. Many of us will remember in the olden days, when the plate lightning arrester was first introduced, these arresters certainly prevented damage to the instruments they were intended to protect, but they generally put the line to earth and caused an interruption of varying duration. This earthing of the line was due either to the carbonisation of the paraffin paper separating the earth and the line plates, or to the fusing of small particles of metal which placed them in contact. I must confess personally that when we first introduced condensers on a large scale in telegraph circuits for quadruplex and other methods of working I rather anticipated that we should get a good deal of the trouble that we had experienced with plate protectors, and I was ultimately glad to find that my fears were unfounded, because although in theory the condenser would represent a very extended lightning arrester, in practice it absorbed the charge without causing a disruptive discharge to earth. We must bear in mind, of course, that an ordinary lightning discharge from a telegraph circuit is, as a general rule, rather an inductive than a direct effect; in other words, when the pressure from a lightning cloud passing over a line of conductors is reduced by a flash of lightning the static stress in the telegraph wire is released, a discharge takes place, and when the end of the wire is connected with a condenser of about the same capacity as itself the discharge harmlessly divides itself between the wire and the condenser. The use of condensers, if I may be permitted briefly to refer to that aspect of the question, has increased marvellously in the telegraph and telephone service. I should not like to say how many millions of condensers are now in use. At all events, every telephone circuit fitted up on modern principles has a condenser in it. They have been largely used for telegraph purposes, and that use is extending day by day, so that I think it is not a very far-fetched idea if I say that we are within measurable distance of having a condenser on every telegraph circuit as we have on every up-to-date telephone circuit. The use of condensers has allowed us to introduce universal battery working on omnibus circuits which had previously to be supplied with independent batteries at every small station. This in itself will involve an enormous economy in telegraph working, and I think it is almost certain that the use of condensers will become universal on telegraph and telephone circuits within a brief period from now. From this point of view, therefore, anything which tends to facilitate their manufacture, to reduce their price, and to render them more stable is a very great advantage to both services.

Mr. Kingsbury.

Mr. J. E. KINGSBURY: It may be interesting if I took a few moments in referring to one or two historical facts in connection with the use of condensers on telephone circuits and the methods of their manufacture. One of the earliest references to the use of condensers on

Mr. Kingsbury.

telephone circuits that I have been able to find is in a patent which was deposited in the United States Patent Office by Black and Roseburgh on June 4, 1878, although it was not issued till February 18, 1879. It was for the use of a condenser in place of a type of apparatus which had been mentioned in a previous specification of Roseburgh's, and it is of interest to note that the type of apparatus which it displaced was practically the same thing as the tube which Mr. Mansbridge has explained to us is used in these high-tension condensers. This was the fourth claim of Roseburgh's U.S. patent, No. 212,510: "In telephony a glass tube (*a*) filled with glycerine and water or other suitable liquid, and provided with air-tight fitting caps (*b b*) connected with platinum points (*d d*) forming a high resistance medium capable of offering high resistance to the galvanic current and comparatively little resistance to the induced current, applied substantially as and for the purpose specified." That was issued on February 18, 1879, and filed on May 25, 1878. A few days later, apparently, he had found that a condenser was far more suitable for the purpose he had in view than the tube of glycerine and water, and the first claim of his second specification (No. 212,433) was: "At any station of a telegraph or telephone line, and on a derived line of the same, the combination of a telephone, with or without other secondary-current apparatus, and a condenser, so that the secondary-current apparatus may be used without interfering with the action of the galvanic circuit and so that the galvanic circuit may be broken between the points where the two ends of the derived line are attached without breaking the secondary-current circuit, substantially as set forth." There might have been some earlier patents, but that is amongst the earliest that I have been able to find. It may be of interest also to note that in that specification a condenser is described as follows: "The condenser is constructed of alternate layers of tinfoil and thin plates of mica, guttapercha, or paper saturated with paraffin, arranged like the leaves of an interleaved book. Each alternate metal plate is connected so as to form a distinct series, and each series is insulated from the other, one of which should in this case be connected with the line and the other with the earth, the telephone being inserted above or below the condenser as may be most convenient, but forming part of the same circuit." That description I think would apply to almost any condenser until about 1896. Condensers were used in telephone working to a small degree only and for very special purposes; no considerable demand had existed for them. But in 1896 the central battery system was being actively developed. The central battery system eliminated the magneto, and hence provided, other things being equal, a cheaper substation outfit. But the condenser of the period was a costly apparatus, difficult to make, and unobtainable in large quantities. I think we may say that the invention of a cheap and practical condenser was as much the invention of necessity as any other invention that we have to deal with. The American Bell Telephone Company found themselves in the position of requiring a cheap condenser, a small condenser, and

Mr. Kingsbury.

a condenser which could be manufactured in large quantities. The demand created the supply. There were three engineers in the employ of the Company, named Lee, Westcott, and Robes,* who tackled the problem and developed a condenser manufactured from rolls of paper and rolls of tinfoil, using machinery for the purpose, very much after the manner that Mr. Mansbridge has shown us in operation this evening. Their method, having been brought to a practical conclusion, supplied condensers for shillings instead of guineas, and permitted the manufacture by millions instead of tens. As Mr. Mansbridge has told us, that was the position of the art when he took a further step forward. It seems obvious that if a single sheet of paper can carry with it the metal there must be an economy; there ought to be greater certainty than in the case of running two separate strips of material, and it seems to me to indicate a very happy thought on the part of the author to bring about that combination. In practice I know there were some difficulties in carrying out the author's work as originally introduced, but I think it was that further happy thought of burning out the faults and applying an apparently destructive current to the substance that put into actual practical shape what before perhaps had something wanting. As between Mr. Mansbridge's condenser and the form previously in use, that is not a point upon which I am in a position to offer any criticism or make any comparisons. There would seem to be an obvious advantage in Mr. Mansbridge's form, and so much is that a matter of our belief that in our London factory we have adopted Mr. Mansbridge's process. If we have not been enabled to convince all other factories of its superiority, perhaps it is only a question of time before we are able to do so.

Mr. Whalley.

Mr. A. WHALLEY: Representing one of the first firms which took up a licence under the author's patent, my experience has been only in making condensers in the rolled form of foiled paper, and having a single interleaving paper half a mil thick between the two foiled papers. Mr. Mansbridge's paper refers primarily to the use of condensers of his own pattern for telephonic and telegraphic work, but they are of some interest at the present moment, one might think, also to electric light engineers, especially as it was recently brought out in the discussion before the Institution on Messrs. Handcock and Dykes's paper on metallic filament lamps that the use for lamp circuits of transformers, or auto-transformers, seriously lowers the power factor of the lighting circuits. These condensers, with only a single interleaving paper, are quite suitable to use in capacities of 10 or more microfarads, and will stand all day long 230 volts with scarcely a noticeable rise of temperature, and could no doubt be made to stand from 450 to 500 volts; at any rate, it would be worth consideration as an attempt to raise the power factor at a comparatively small cost. As regards the breakdown point mentioned of 150,000 volts per centimetre for the metallic foil condensers, our own practice

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* Lee, Westcott, and Robes U.S. patent is No. 575,653. Filed July 8, 1896. Issued January 19, 1897.

Mr. Whalley

in the shops at Helsby is to strain these condensers with a direct current of 500 or 600 volts sent through a commutator to give a flat-top curve, alternatively positive and negative; we sort out the weak or defective condensers by that pressure and they stand it for a long length of time. The "degree of electrification" which Mr. Mansbridge mentions at page 557 as falling seriously with a rise of temperature is, as Mr. Mansbridge mentioned verbally to-night, the percentage fall of electrification. Apparently the temperature coefficients which are given on the last page for correcting the megohms do not apply when correcting the percentage fall of electrification, but it is not quite clearly stated. Frequently the condenser shops are at high temperature, something like 85° F.; and it would be of interest if it could be brought out in the discussion whether temperature has also a serious effect, under the National Telephone Company's Specification, on the difference between the observed capacity measurement with direct current and with alternating current. The formulæ given on page 559 for measuring the megohms per microfarad of the condenser are interesting. They are, I presume, the maximum possible figures, and not the specification figures. Apparently they are based on something like 1,750 megohms per microfarad at 60 degrees at a pressure of 300 volts. The Post Office Specification gives a figure of 1,000 megohms per microfarad for telegraph condensers, and for telephone condensers about 300, so that different constants will be needed to get the specification figures. Artificial cables will be, I believe, of very great use to technical colleges if they lay themselves out to cultivate and spread a knowledge of the telephonic art, as Mr. Gill hopes, and they will soon be on the market at a reasonable price, up to sixty or more miles. The author's process has become the standard on the Continent, I believe, and in Great Britain, and possibly it will soon become the standard also in America.

Major O'Meara.

Major W. A. J. O'MEARA, C.M.G.: It may be of interest if I gave a few statistics as to the use of condensers in the Post Office. During 1906 there were issued for telephonic use 14,130 condensers, representing 32,200 microfarads; last year there were issued 14,800 condensers representing 33,550 microfarads. It may be of interest to know that at present we have in use on our telephone circuits some 80,000 condensers representing 0·18 farad. Sir John Gavey referred to the increasing use of condensers for telegraphic purposes, and I have a few figures in relation to that matter too. In 1906 we issued 2,130 condensers, representing 15,270 microfarads; last year we issued 2,470 condensers representing 12,130 microfarads. I am sorry to say I have not the exact figures relating to the total number of condensers in use on telegraphic circuits, but I understand that we have in this country 6,000 condensers.

I may say the figures I have mentioned refer to paper condensers manufactured as described by Mr. Mansbridge. We have had these condensers in use now for seven years, and I think I can support Mr. Mansbridge in his claim that they are satisfactory from every

Major O'Meara.

point of view; that is to say, we have not found them to fail from loss of insulation or in any other way.

Mr. Cohen.

Mr. B. S. COHEN: There is one important point that Mr. Mansbridge does not refer to in his interesting paper, and that is the effect of alternating current on condenser capacity. It will be seen that, in the National Telephone Company's Specification for condensers, a reference is made in the first clause to a test with both alternating current and with the ordinary discharge method. Many forms of commercial condensers possess considerable dielectric losses, which result in a reduction in capacity, when measured by alternating current, to such an extent as to cause serious trouble. The necessity for testing condensers in practice with alternating current was, I think, first pointed out by the Engineering Staff of the Western Electric Company. A few years ago an investigation was carried out in the National Telephone Company's laboratories to determine the capacities of various types of commercial condensers at telephonic speech frequencies, and perhaps a few of the results may prove of interest. A batch of condensers of one pattern, with a mean discharge capacity of 2·09 microfarads, when measured by alternating current of 800 ∿, had a mean capacity of 1·76, or a percentage variation of 18·8. Another batch, when measured by discharge, had a percentage increase of capacity amounting to just under 1 per cent.; a further batch with an alternating-current capacity of 1·81 microfarads had a discharge capacity of 2·43, or 34·2 per cent. increase. One condenser tested had actually an alternating-current capacity of 0·6 microfarad, and a discharge capacity of 1·88 microfarad. From these figures it will be seen that the variation may be considerable, and, despite the fact that these condensers might have been accepted as satisfactory under a specification which only covered discharge capacity, insulation, and breakdown tests, many of them would give very serious trouble when installed in telephone instruments or circuits. Only a few condensers of the Mansbridge type have been tested and these do not show any great variations, though those made by the G.P.O. were apparently superior to those made by outside firms. It would not appear that, provided the foil is of negligible resistance, this type of condenser should vary more than the ordinary pattern. I might mention that, given an alternating current of about 800-∿ frequency, the workshop capacity test on condensers with this current is, if anything, simpler than the corresponding direct-current test, as all that is required is a standard condenser, slide-wire bridge, and a telephone receiver. The question of insulation-resistance variation of commercial condensers with alternating current does not appear to have been studied to any very great extent, and I should like to ask the author if he can give us any information on that subject. The tests for this, involving as they do measurements of very small power factors, are more difficult to make commercially than the corresponding capacity tests, which, I think, in all probability cover the effects. In this connection I should

Mr. Cohen. like to refer to the artificial cables for telephone work that were mentioned by Mr. Mansbridge and also by Mr. Whalley as being shortly ready for the market. Whilst probably of great use for educational work, I should think it very possible that such cables might introduce some dangers in use. The general type of artificial cables manufactured for actual telephone work have the capacity and resistance lumped to such an extent that the result is the same as if they were evenly distributed within a very small percentage. Such artificial cables, if manufactured with silvered mica condensers, act almost in the same manner as telephone dry-core cable, as the latter shows very little variation in capacity with alternating current. If artificial cables, however, are manufactured with capacities made up with paraffined paper, care would have to be taken to avoid trouble caused by variations in capacity.

Mr. Oppenheimer. Mr. H. OPPENHEIMER: As far as I am concerned, I can congratulate Mr. Mansbridge on the progress he has made since I first saw his apparatus, two years ago. There is no doubt that to-day the manufacture of the telephone condensers is merely a matter of practice. The elementary stages have been solved by Mr. Mansbridge, and those firms which have taken up the manufacture have been initiated in such a perfect manner that even at the very start the relative results are very satisfactory. I remember that from the first batch of condensers we made we had about 7 per cent. "wasters"; in the second lot we brought the figure down to 3·8, in the third batch to 1·6, the next to 0·36, and to-day we have arrived at 0·2. It is remarkable when one compares the various specifications to see how the telephone departments who have most common battery experience have come practically to the same conclusion, and have fixed the tests almost alike. As far as the pressure to be applied is concerned, I think the G.P.O. Specification prescribes 300 volts, the National Telephone Company 400 volts, the Colonies 1,000 volts, and the Continent 350 volts. The time during which the test is applied is, in the G.P.O. two minutes, the National Telephone Company half a minute, the Colonies five minutes, and the Continent one minute. The insulating resistance is, in the G.P.O. 300 megohms, the National Telephone Company 200 megohms, the Colonies 1,000 megohms, and the Continent 400 megohms. These figures appear to show that, although the Colonies are at the present moment endeavouring to take advantage of the experience gained on this side and to introduce common battery working, still they are placing certain restrictions round the attributes and devices used in connection therewith which are certainly detrimental to progress. To require that an ordinary telephone condenser should withstand a 1,000-volt pressure for five minutes and that its insulation resistance should be 1,000 megohms is practically nullifying the efforts and the progress made by Mr. Mansbridge.

Mr. Taylor. Mr. J. E. TAYLOR: In connection with high-tension condensers of the silvered Leyden jar type to which Mr. Mansbridge refers in the earlier part of his paper, I have had some experience with these for

Mr. Taylor.

wireless telegraphy purposes which may be of interest. Some years ago, before the Moscicki condensers were put on the market, I had several experimental Leyden jars made with coatings of chemically deposited silver, and though they had some advantages over the usual tinfoil-coated jars, particularly as regards efficiency in producing electrical oscillations, they also had some serious drawbacks. The silver coating was very easily damaged, either mechanically or electrically, in the latter case by an effect very similar to that producing the "self-sealing" quality in the Mansbridge foiled paper condenser. It was found difficult to make secure connections to the silver coatings of such a nature that no sparking occurred at any point of connection, and so soon as the minutest trace of sparking occurred the silver was rapidly eaten away. In other cases accidental sparking to neighbouring wires or other conductors produced the same effect, which, if unobserved, quickly caused erosion of considerable areas of the coatings. Backings of electro-deposited copper and of celluloid varnish were tried but did not prove altogether satisfactory. The copper coating on the curved surfaces of a Leyden jar is liable to become detached and peel off, while the varnishes do not afford complete protection from the sparking trouble. A similar erosion also occurred at the upper edges of the coatings due to the well-known "brush" discharges which take place there. In connection with these brush discharges from Leyden jars which are a source of damping losses in the oscillating circuit of a wireless telegraph transmitter, I do not remember to have seen a really satisfactory explanation of their cause; the usual explanations based upon the surging of the charges round the circuit or the decrease of specific inductive capacity of glass at high frequencies of alteration are not adequate. The matter, it seems to me, is best explained as an effect of ionisation of the air at the edges of the coatings. Successive oscillations during the period of discharge build up the ionisation which facilitates and augments the discharges primarily due to the density of the electric field at the edges. This will account for various effects observed, notably that the more sustained the oscillations the more pronounced do the brush discharges become. This view also fits some of the effects noticeable in improperly adjusted spark gaps in wireless transmitters when the conditions are such that the first rush does not create a spark, but perhaps causes a brushing or spitting discharge which, after a fraction of a second, ionises the air sufficiently to facilitate the formation of the main spark, weakened, however, to an abnormal extent by the energy absorbed in the first part of the process.

Reverting to the Mansbridge foiled paper condenser, I can support some of the advantages claimed for the self-sealing quality of these appliances. I have found it possible to make efficient and satisfactory use of them for spark-suppression in a circuit containing a strongly energised electromagnet where a condenser of the older type and having the same capacity would not stand a single rupture of the circuit. With the Mansbridge condenser there is less chance of perforation of the

Mr. Taylor. dielectric, and when it does occur it does not perceptibly impair the condenser. Indeed, there is no doubt that a very large number of these perforations must take place before the condenser is rendered useless. Its replacement then would not be a matter of serious expense in view of the cheapened process of production.

Dr. Silvanus Thompson. Dr. SILVANUS P. THOMPSON: I have nothing to say beyond expressing in common with all of us, the admiration we have for Mr. Mansbridge's work. But as I am ignorant on the subject of the modern condenser, I feel disposed to ask two questions. In the first place, we saw a strip exposed to the test flashing with sparks as all the faults in the paper and at its edges were discovered by the machine and burnt out. I want to know what will happen if that paper is sent through a second time. Will it flash at all, or will it flash much or little? Does the flash successfully burn out all the faults or find some more a second time over? The other question is this: It was an exceedingly interesting physical fact to be told that the metal-deposited paper before being calendered was almost a perfect non-conductor. I want to know whether it, in common with other metallic films that are made of bad-conductivity materials, becomes a better conductor in the presence of electric oscillations; in fact, would a strip of that uncalendered paper act as a coherer and become as a conductor? I have been making some private inquiries of my friends sitting near me of how much a microfarad costs nowadays. I am the possessor of various microfarads, and the dearest condenser I ever bought—it was only one-third of a microfarad—I paid two and a half guineas for. At that rate a whole farad would have cost about £7,870,000, but I fancy nowadays a farad could be bought for something like £50,000.

Mr. Mordey. Mr. W. M. MORDEY: The author has clearly made an important advance in the construction of condensers. I wish to ask some questions directed particularly to an aspect of the subject on which I once tried to do some work. I refer to energy loss in dielectrics. Some years ago I read a paper* here on dielectric losses in cables. I was unfortunate enough to make my experiments on a rubber cable which had the exceptionally high power factor of something like 0·1, and I was led to draw certain general conclusions as to losses in cables due to this cause—conclusions which were much too high for cables such as are now generally used. But on going into it later I found that the dielectric hysteresis loss, in even the best cables that can be obtained, is so high that under certain conditions it may cause more waste of energy than the current through the copper. It would be very interesting if the author, who evidently has exceptional facilities, could go into the question of the losses in dielectrics. With regard to the Moscicki high-tension condenser shown by the author, it would be easy to test that, as it seems to be provided with a water circulation which might be intended for the very purpose of determining the losses by measuring the amount and rise of temperature of the water. I should

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* "Capacity in Alternate Current Working" read Jan. 10, 1901 (*Journal Institution of Electrical Engineers*, vol. 30, p. 364).

Mr. Mordey

not expect to find a lower power factor than 0·03. At that power factor the loss at 50 ∿ and 1,000 volts would be 10 watts per microfarad, at 10,000 volts the loss would be 1,000 watts, and so on. Such losses may affect the question of the use of condensers on power circuits; in any case it would be well to know what they are. Some time ago I tried to get some idea of how that loss was caused, and I made the suggestion that the mere static attraction between the electrified surfaces, being often repeated as it is with alternate currents, is in itself sufficient to account for a good deal of what we call the dielectric hysteresis heat loss. It may be largely mechanical. For example, if my arithmetic is not wrong, with a 20,000-volt condenser or cable and a dielectric 0·2 inch thick, the static attraction is about 2 lbs. per square foot. This repeated 100 times a second on any dielectric may account for a good deal of heat. Applying that idea to the interesting example the author gives and illustrates in connection with Fig 6, of the breakdown of a condenser at 1,200 volts, assuming that the thickness of the dielectric is about 0·001 inch (which I think from an earlier part of the paper is right), the actual pressure between the metallic films in this condenser due to electrostatic attraction may be about 200 lbs. per square foot or 1·4 lb. per square inch. True, the attraction may be to a certain extent balanced at the two sides of a film of a condenser, but where it is not balanced the pressure alone may be quite large enough to account for a breakdown.

The President.

The PRESIDENT: During the war in South Africa we, the Corps of Electrical Engineers, used the Swedish cavalry pattern telephones which contained condensers, and that this outfit enabled us to do exceptionally good service by enabling speech to be carried on through fine wire uninsulated metallic circuits laid from bicycles on the bare Veldt, and that the condenser attachment was, I believe, the cause of our being able to make ourselves heard and understood even if these circuits were broken by cattle or other means tearing them apart; in several instances we obtained audible speech although the gaps must have been many feet in length, and we know that we could signal buzz-messages through many yards of such breaks. This fact was of national importance, as at a time when the telegraph service had been destroyed we maintained communications and hence were able to relieve a good deal of anxiety at home while the telegraph lines were being repaired, as these telephone communications were the only connection between the Army in front and Capetown.

Dr. Russell.

Dr. ALEXANDER RUSSELL (*communicated*): The paper is of special interest to me as the data given throw light on some curious phenomena in connection with the use of condensers in laboratory work which I have noticed. It follows from Kelvin's criterion for an oscillatory discharge that when the resistance of the ballistic galvanometer used to measure the discharge of a condenser is sufficiently small the discharge will be oscillatory. In this case we would expect that the galvanometer would act in a curious way. When investigating these effects I discovered that certain needle galvanometers had " dead

Dr. Russell. points" for transient currents. I have found, for example, with those galvanometers that if the needle be at a "dead point" it will remain stationary however great the discharge that passes through the galvanometer coil. If we diminish the resistance in series with the condenser, we get a large throw in one direction, but if we increase it we get a throw in the other direction.* In some positions of the needle the throws on charge and discharge are in the same direction, whilst in others they are in opposite directions. The phenomena, although fairly complicated, can be explained easily and satisfactorily if we assume that an ordinary condenser acts like an ideal condenser with a non-inductive resistance of a few ohms in series with it. So pronounced is this effect that I find it useful to classify condensers according to the magnitude of this "effective" internal resistance. In some condensers this effective resistance is large, and they are not suitable either for measuring inductance in terms of capacity and resistance, or for producing Duddell currents. Probably those unknown causes which are generally classified under dielectric hysteresis and absorption have something to do with this effect, but I have always held that it is mainly due to the resistance of the sheets of foil used in making the condenser, and a perusal of this paper confirms me in this opinion. I think that if efforts were made to have the conductivity of the foil as great as possible a thoroughly satisfactory condenser suitable for measurements with high-frequency currents could be produced.

The effect of the resistance of the foil can be discussed mathematically. To simplify the theory let us consider a condenser made up of two long strips of foil having terminals at their ends, and separated by a dielectric of high insulativity and in which the absorptive effects are negligible.

Electricians customarily assume that the formula to give the capacity K in farads, when the voltage is sine-shaped, is $K = A/\omega V$, where V and A are the effective values of the voltage and current respectively, and ω is 2π times the frequency. The true formula for this case may be shown to be †—

$$\frac{A}{\omega V} = \sqrt{\frac{K}{\omega R}} \left[\frac{\cosh y - \cos y}{\cosh y + \cos y}\right]^{\frac{1}{2}},$$

where $y = \sqrt{2\omega K R}$, and R is the resistance of the two strips of foil in series.

Provided that y be not greater than unity, that is, provided that $2\omega K R$ be not greater than unity, we may write with high accuracy—

$$\frac{A}{\omega V} = K\left(1 - \frac{7}{90}\omega^2 K^2 R^2\right).$$

If we had a non-inductive resistance R_1 in series with an ideal condenser K the corresponding formula would be—

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* *Phil. Mag.* [6], vol. 12, p. 202, 1906.

† Russell, "Alternating Currents," vol. 2, p. 471 (48).

Dr. Russell.

$$\frac{A}{\omega V} = \frac{K}{(1 + \omega^2 K^2 R_1^2)^{\frac{1}{2}}}$$

$$= K\left(1 - \frac{1}{2}\,\omega^2 K^2 R_1^2\right),$$

approximately, when $\omega K R_1$ is small. If we assume that $R_1 = (7/45)^{\frac{1}{2}} R$ the formulæ become identical. Now, the smaller the resistance in a circuit the more nearly does the oscillatory discharge current assume its limiting form of a sine-shaped alternating current. Hence the mere fact that the capacity of condensers must be regarded as distributed capacity suffices to explain some of the phenomena observed in practice. It also points out a serious limitation to the use of condensers with high-frequency alternating or pulsating current for testing purposes, when the highest accuracy is desired.

Mr. Ashton.

Mr. A. W. ASHTON (*communicated*): Though the method of specifying insulation resistance as the ratio of the testing voltage to the current entering the condenser after one minute's electrification is convenient in practice, yet the figure so obtained is certainly not a resistance. The current from which the true resistance of a dielectric may be calculated should represent energy converted into heat in the dielectric, which energy is not recoverable on discharge. From experiments which I have made on foil-paper condensers I have found that the current entering the condenser after charging has been continued for 72 hours is only about 5 per cent. of the current at one minute's electrification: also after charging for a long period the curve of discharge current becomes approximately the same as the curve of charging current. This is very important, and shows that nearly the whole of the quantity entering the condenser during electrification represents recoverable energy. Since the difference between the energy absorbed and that given out represents the amount converted into heat, it is evident that this latter must be very minute and the true resistance of the dielectric very high. I have shown elsewhere (see *Phil. Mag.*, November, 1901) that for certain dielectrics the current representing the absorbed energy may be represented by an expression of the form $K t^{-x}$ where $K =$ a constant, $t =$ time since commencement of charge, and the exponent x varies from 0·43 to 0·78. With foil-paper condensers I have found that this law is only approximately true, and the exponent of t varies from 0·53 to 0·58. The author's equations on page 559 confirm this figure, as the exponent of the time in these equations is 0·5.

With regard to the discrepancy noticed by Mr. Cohen between the values of the capacity as measured by alternating and direct currents, there is no doubt that the quantity discharged from the condenser is a function of the time of *discharge*. The capacity calculated from a discharge lasting, say, $\frac{1}{1000}$ sec. must differ considerably from that determined by means of a ballistic galvanometer. In fact, if it were possible to use a galvanometer which would integrate the discharge

Mr. Ashton. for the first ten minutes the capacity so determined would be nearly doubled.

Dr. Sumpner. Dr. W. E. SUMPNER (*communicated*): There is no doubt that the applications of condensers to power installations using alternating currents would be both numerous and important if the condensers could be made sufficiently small, cheap, and safe. In each of these three respects the Mansbridge mode of manufacture is a decided step in advance, but I should like to emphasise the matter of safety. The author, having in view mainly applications to telegraphy and telephony, has, I think, not sufficiently dwelt on the question of safety. The self-sealing property of these condensers is closely analogous to that of oil insulation for high-tension transformers and switches. Hitherto condensers for power purposes have been mainly of the electrolytic type, and their high power factor and sloppy character render them unsuited for engineering purposes. Other condensers have been liable to breakdowns causing serious short circuits. But the condensers now described act as automatic cut-outs if from any cause they break down. The high resistance of the metal films prevents serious currents passing, and the breakdown current merely causes a rupture of the electrical connections. In this respect these condensers seem safer than choking coils, for if a fault develops in the latter a serious short usually occurs. During the last two years I have largely used these condensers for voltmeters and phasemeters of the type recently described by Mr. Record and myself. We have already pointed out that one of these instruments is admirably adapted to the rapid measurement of the true capacity of such condensers. But the point I wish to make is the fact that during a large amount of testing spread over two years there has been no case of a short circuit due to the subjection of such condensers to alternating voltages (I have not used pressures above 400 volts). Several cases have occurred in which the capacity has considerably fallen off. But these cases can fairly be attributed to faulty manufacture resulting in the formation of cracks in the thin metal film, such cracks ultimately becoming ruptures under the action of the current. The better condensers, sorted after subjecting them to alternating voltages for several hours, have in no case, so far as I have been able to detect, altered their capacity in the slightest degree owing to the action of alternating current, even when frequently used with such currents over a period of eighteen months.

Some of the time-honoured modes of testing and specifying the properties of condensers need revising now that Thomson galvanometers and electrometers are no longer the only, or the best, instruments for making condenser measurements. The three important properties of a condenser are its capacity, its insulation resistance, and its power factor. The phrase "megohms per microfarad" may be usual, but is both a clumsy and inaccurate term for its time-constant in seconds. The capacity can now be quickly tested by a non-reflecting instrument. The insulation can as easily be tested by permanent magnet voltmeters and micro-ammeters. The power factor is more difficult to measure, but is

Dr Sumpner.

the best and least fanciful way of summing up the absorption properties of the condenser. I should like to draw attention to a very useful paper on condensers by F. W. Grover,* who has tested a large number of mica and paraffin-paper condensers obtained from various makers in Europe and America. The results are of interest. The alternating current through a condenser differs from exact quadrature with the volts by a small angle θ such that $\sin \theta$ is the power factor. Out of 54 mica condensers of various makes the value of θ for 18 (or one-third of these) varied from half a minute to 3½ minutes. For 36 of the condensers (or two-thirds) θ was less than 17 minutes, and for 11 out of the other 18, θ was less than one degree. The remaining 7 condensers were bad. This means that the power factor for 47 out of the 54 mica condensers was less than 0·0175, for two-thirds it was less than 0·005, for one-third it was less than 0·0011, while in one case the power-factor was so low as 0·0002. Similarly out of 20 paraffin-paper condensers of various makes the power factor for two-thirds was less than 0·02, and for one-third less than 0·006, while the lowest was 0·0017.

Some of these results may need confirmation, for Mr. Grover's methods of test were most complicated and laborious, and few experimental details are given. But there can be little doubt about the diversity of the results. The various values for the power factor can hardly be attributed to differences in the dielectric; they are much more likely to be due to the conducting surfaces. The loss of power due to the resistances, or to minute arcs, in such surfaces is probably the most serious part of the condenser loss. The views that have been advanced about dielectric hysteresis appear to me to be purely imaginary. In any case the power-factor of reasonably well made condensers is so low that the loss of power is negligible for engineering purposes. Size, price, and safety are the only important matters.

Mr. Stubbs.

Mr. A. J. STUBBS (*communicated*): I am disposed to think that the "breaking down" effect is probably due to the presence of metal-filled perforations rather than to sparking over simple air-gaps and subsequent fusion of the surrounding metal, but it is likely that an observer of Mr. Mansbridge's calibre will be able to remove one's doubts about his theory.

He himself, however, seems to think that breakdown of the more robust type of metal-foil condenser must be accounted for on somewhat different lines. Of course, the use of two thicknesses of paper instead of a single piece of double thickness is a precaution against the occurrence of flaws in manufacture, but breakdown with two thicknesses cannot be attributed to a flaw in each coinciding. I think that perhaps the idea of the presence of *conducting* flaws in the paper may be strengthened by recent experience with our paper-insulated cable. In one case a whole delivery from the paper mills was found after manufacture of a considerable length of cable to contain conducting particles which, in favourable circumstances, broke down the insulation of the cable.

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* Washington Bureau of Standards, vol, iii. No. 3.

Mr. Stubbs.

"Megohms per microfarad" like "Megohms per mile" seems too expressive a term for the practical man easily to give up in favour of the somewhat more correct "Megohm-microfarad."

In regard to the melting or setting point of paraffin wax, I do not understand Mr. Mansbridge to mean that in practice his normal test takes thirty minutes? An equally satisfactory and much speedier method is to place a small tube partly filled with wax against a thermometer and heat the two in water, observing the temperature when the wax begins to rise in the tube. The longer method is certainly interesting, but is—as is implied in the paper—not that used to obtain the (probably equally accurate) melting points specified by the dealers.

The great variation of insulation per degree of temperature, if unquestionable, certainly makes one glad that the question of insulation is not of prime importance. It would be interesting to know, however, if the tests made were absolutely conclusive.

Mr. Mansbridge's work has been an important factor in the extension of the now almost universal adoption of common battery working, and it may perhaps be news to him to hear that condensers may prove at no distant date the salvation of the telephone system itself! Recent experience shows that the telephone acts as a sort of spark-gap for the oscillatory currents of radio-telegraphy, resulting in the breakdown of the telephone. With cheap condensers the telephone engineer may view the installation of a wireless station by the Admiralty in the heart of London with comparative complacency when he knows that the 5 farads which according to Mr. Mansbridge can be manufactured in a year would suffice to protect a hundred million telephone circuits from this latest and most insidious enemy, as a condenser of only 0·05 microfarads put across the circuit is found to prevent sparking. It is possible even that the capacity of the leads will prove to give sufficient protection.

Mr. Addenbrooke.

G. L. ADDENBROOKE (*communicated*): Some recent work of mine on the behaviour of dielectrics under high alternating stresses bears on points dealt with in Mr. Mansbridge's interesting paper.

For convenience of experiment some of my work has been done with condensers having tinfoil electrodes, and I have come across and employed the interesting self-sealing property to which Mr. Mansbridge alludes. It was convenient chiefly because in breaking down insulation its use prevented such serious arcs as when solid metal plates are employed. Mr. Mansbridge is much to be congratulated on his practical application of this property.

Mr. Mansbridge's work does not appear to have led him, so far, seriously to consider the losses in the dielectric when submitted to alternating pressures over considerable periods and the heating which then occurs, which, as well as the cost of manufacture, has been the chief deterrent to the use of condensers hitherto in connection with the transmission and use of alternating currents for power supply; but an intelligent commencement of manufacture having been made, we may undoubtedly look for developments in this direction. It will, however, be a condition that such condensers must have small dielectric losses. Mr. Addenbrooke.

For some time I have been impressed with the value of measuring the losses in dielectrics, not only for their importance in themselves, but because so much other information regarding the behaviour of the dielectric under different conditions can be obtained in this way. The initial difficulty has been, however, to find a satisfactory way of measuring these losses, as has already been mentioned. I have accordingly devoted a good deal of time to working out a method of measurement applicable to small capacities or short lengths of cable. As a result I am glad to say that by the use of the electrostatic wattmeter which I brought out some time since, with certain modifications, it is possible to measure the losses in capacities as small as $\frac{1}{1000}$th. of a microfarad and at any voltage which may be required from, say, 500 volts upwards and at very low power factors. With this apparatus I have been able to secure some interesting results which I hope to make public shortly. One or two points, however, may be mentioned. There are, as has already been hinted in the discussion, great differences in the losses which occur in condensers and cables, depending on their construction. For instance, in a paper condenser kindly lent to me by Dr. Muirhead the loss is as low as $\frac{3}{4}$ of 1 per cent of the apparent loss, which means a loss of about 3·5 watts in a 1-microfarad condenser submitted to an alternating current of 83 periods and 1000 volts. This is the best result I have come across so far, but in most cases the losses are much larger and with bad construction may amount to 30 per cent to 40 per cent. It must be borne in mind also that the charge of the condenser depends on the shape of the alternating wave, and with a high peak the current flowing in and out of the condenser is larger than would be deduced from the voltmeter reading which reads the root of mean square of the volts. Consequently the capacity appears higher. In fact, a measurement of the current flowing into a condenser of a known capacity at a certain voltage as measured by the voltmeter may be used as a rough indication of the shape of the alternating wave. It may be that some of the discrepancies in Mr. Cohen's results can be accounted for in this way.

Mr. Record.

Mr. J. W. RECORD (*communicated*): I am inclined to take exception to the word "foiled paper," which Mr. Mansbridge uses throughout his paper to distinguish the new type from those containing tinfoil plates. The word "foiled" is not sufficiently comprehensive, and is likely to cause confusion, and as the paper is actually painted, or coated with a metallic film, the word "coated" paper would be more applicable for the metallic painted type and "tinfoil" condensers for the foil plate pattern.

Condensers with coated plates are to be recommended for the ease with which they can be wound, and for the reduction in the weight of material. I am not, however, in entire agreement with Mr. Mansbridge regarding the pressure to be applied to a particular plate. With a tinfoil condenser the foil, being laid on separately, cannot be in such perfect

Mr. Record. cohesion with the dielectric as is the case with the coated paper, therefore an increase of pressure in the former will have far more effect than in the latter. Mr. Mansbridge prefers to leave the pressure applied to a plate to the discretion of the operator, rather than to work to gauges. Personally I prefer to eliminate the human element as far as possible, and from the above considerations it will be seen that if a small variation in pressure does result, the capacity will not be materially affected. Moreover when working to gauges a far lower rated operator can be employed on the work.

I have measured the resistance of a 2-microfarad condenser of the "coated" type, containing 50 ft. per plate $3\frac{1}{8}$ in. wide, and find it to be about 90 ohms. A similar length of "tinfoil" paper has a resistance of 3·75 ohms. This question of resistance is of great importance when the condensers are required for the suppression of sparks on high-speed tremblers, such as induction coils, and I have found that a coated paper condenser must either have several contacts on each plate for reducing its resistance, or else a condenser of larger capacity than would be necessary in the tinfoil type must be used. This brings us to a point of vital importance, both with regard to the testing and specifying of condensers. Evidently the National Telephone Company are alive to this fact, as their latest specification provides for a test approaching working conditions.

The continuity of a coated condenser may be impaired through imperfect painting or creases at the folds, and the test employed should thoroughly search for these faults. This cannot be done with a continuous current test, for provided the circuit of the plate is not altogether broken the condenser will receive its full charge.

By far the most satisfactory means of measuring capacity known to me has been devised by Dr. Sumpner, and is described in a paper by Dr. Sumpner and myself, recently read before the Institution.*

Comparing the condenser current during test by the National Telephone Company's method with the alternating-current voltmeter method, referred to in that paper, and neglecting the resistance of the plate, we have—

$$C = E\,p\,k = 0{\cdot}0503 \text{ ampere}$$

in the former, and 0·125 ampere in the latter case, or $2\frac{1}{2}$ times as much (100 volts and 100 $\sim$).

The alternating current voltmeter method enables a far more searching voltage to be applied during the test and a frequency that can be obtained without ordering a special alternator, and gives a current that will effectually burn out weak portions of the plate due to creases and other causes.

If the condenser is leaky, whether intentionally or not, true capacity is still registered on the instrument, because the leakage current, being in phase with the voltage, is nearly 90° out of phase with the

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* *Journal of the Institution of Electrical Engineers*, vol. 41, p. 227, 1908.

Mr. Record.

moving coil current, and can have no effect on the deflection of the pointer. The method is one of comparison with a standard condenser, and the formula is similar to the ballistic galvanometer formula and is explained fully in the paper referred to above.

The tests below were made on some 2-microfarad coated paper condensers. It is noticeable that in all cases the alternating-current voltmeter method shows a lower capacity than the ballistic galvanometer test.

Condenser No.	Insulation Resistance in Meghoms.	Ballistic Galvanometer.	Alternating Current, 100 Volts, 50 Cycles.
1	300	2·00	1·980
2	400	1·90	1·860
3	300	1·85	1·820
4	300	2·15	2·100
5	300	2·00	1·975
6	400	2·30	2·280
7	450	2·00	1·950
8	500	2·00	2·040
9	500	2·00	1·960
10	500	1·80	1·770

Mr. Mansbridge.

Mr. G. F. MANSBRIDGE (*in reply*): I have first to thank the various speakers for their interesting comments on the paper.

Mr. Whalley raised the point as to the use of these cheap condensers for improving the power factor on distributing networks containing many small house transformers. I think that is a very happy suggestion, and I presume it is intended that the consumer who pays for the transformer should pay for the condenser. Then the question was raised as to whether the formula on page 559 is applicable to electrification. The answer is that it deals with megohms only. The variation of electrification with temperature is a problem which up to the present I have not had an opportunity of minutely scrutinising. These formulæ are based upon average results obtained with first-class manufacture, but the Post Office specification figures allow a considerable margin below.

With regard to Mr. Cohen's remarks, I had intended to deal with the alternating-current problem in my paper, but Mr. Cohen was kind enough to say some time ago that he intended to discuss the paper, and knowing how much attention he had given to this side of the subject, I purposely left the matter open, hoping to hear from Mr. Cohen the answer to the question he has now raised. At the Post Office factory we have tried alternating current in comparison with direct current, and although it seems rather like an advertisement, I must say that we have found that our condensers are so good that the difference between the results obtained with alternating and with

Mr. Mansbridge.

direct current is so small as to be scarcely measurable. I should point out, however, that our conditions are somewhat exceptional, inasmuch as we make practically the whole of our condensers, whereas Mr. Cohen has, I think, to deal with quite a number of manufacturers, of whom few, if any, have had the advantage of that long experience of condenser manufacture which has fallen to the lot of the Post Office factory.

With regard to the relative advantages of alternating and continuous-current tests for condensers, I should like to clear up a detail upon which there may be some misconception. Mr. Cohen points out that a defective condenser may have with alternating current an effective capacity which is only a fraction of its normal capacity, and he remarks that this defect is not shown up by the discharge capacity and insulation tests as taken by continuous current. This statement is perfectly true so far as it goes, but one important point has, I fear, been overlooked, namely, that the insulation test with direct current as ordinarily taken gives not merely a measure of the insulation, but a measure of the electrification as well, and it is by its electrification that a condenser shows its quality even more than by its insulation *qua* insulation.

In my experience the defect of low effective capacity with alternating currents is invariably shown up under the direct-current test by the failure of the condenser to electrify properly; that is to say, the deflection, instead of decreasing in proportion to the square root of the time as it should do, will decrease to a much less extent, or will indeed "open up"—that is, will increase rather than decrease. I should like, therefore, to emphasise very strongly the importance of the electrification stipulation in a condenser specification.

One point of warning with respect to tests with alternating current might here be mentioned. When using the slide wire, telephone receiver, and standard condenser referred to by Mr. Cohen, it may be found that no sharp dead-point is obtainable on the slide wire. The reason is fairly obvious, namely, that the phase relation of the currents in the two condensers is disturbed by one having a higher conductor resistance than the other. The standard condenser is usually made from sheets of tinfoil bunched together, and not by the rolling process; consequently the joint conductor resistance of the electrodes is extremely small, whereas with rolled condensers, particularly those of the coated paper type, the resistance of the strip may be a matter of several ohms.

In such a case it is necessary to insert a resistance in the standard condenser circuit before a good balance can be obtained, but the most satisfactory plan is carefully to standardise a rolled condenser and then to employ the latter as a sub-standard. By this means it is easy to get a dead sharp balancing position.

With regard to the variation in the capacity of artificial cables manufactured from coated paper, I would say that so far no difficulty has been experienced in this direction, but it is fair to say that the first cables so made are barely three years old.

With respect to the measurement of very small power factors, I

Mr. Mansbridge

would say that in addition to the pamphlet referred to by Dr. Sumpner, another publication from the same office, but of rather later date, written by Professor Edward B. Rosa and entitled "Wattmeter Methods of Measuring Power expended on Condensers and Circuits of Low Power Factor," is of considerable interest and value in this connection. Copies of this pamphlet bearing the serial number 18, and also of the one by Mr. F. W. Grover, numbered 64, can doubtless be obtained on application to the Bureau of Standards, Washington, D.C. By the courtesy of Professor Rosa I have had the privilege of examining the apparatus used for these tests, and have nothing but admiration for the beauty of the methods and for the concordant results obtained.

With regard to Dr. Thompson's inquiry as to what happens if the coated paper is put through the break-down machine a second time, I have to say that this partly depends upon the voltage employed. If this is low, say 50 or 100 volts, there is practically no sparking at the second time of asking, but if higher pressures are employed, say 200 volts and over, the strain approaches the critical point of breakdown of the normal dielectric, and a certain amount of sparking is bound to occur each time that the paper is drawn over the rollers. I have not, however, been able to find any advantage in running the paper through the break-down machine more than once. My view of what takes place is that the defects which are burnt out the first time are the serious faults such as would be occasioned by the tin mud penetrating wholly or partly through the paper at a pinhole or a weak place in the body paper, or by a grain of metal, large as compared with the particles of tin powder, being driven into or through the paper in burnishing.

With regard to the uncalendered paper acting as a coherer, I cannot say for certain, but I am extremely doubtful, whether it could be made to act in the way suggested, but a strip of calendered paper, which has been so sharply creased as to become practically a non-conductor, can be made to act as a coherer.

With respect to Mr. Mordey's remarks concerning the Moscicki condenser, some results on the lines indicated will probably be made public very shortly, as I understand that a paper on the subject is to be submitted to the Institution. There would seem to be a good deal of truth in Mr. Mordey's suggestion that the dielectric loss may be partly mechanical and may be due to the oft-repeated blows on the dielectric. In those cases where the layers of dielectric have not been solidly cemented together there is no question but that the loss is partly mechanical, as the condenser can be heard and felt to be in vibration, and if the current is of high frequency a loud and distinct note will be produced by such an ill-made condenser. This emphasises the necessity already alluded to for so pressing and cooling the condensers that sufficient wax is retained in the plate. A properly constructed condenser of flat form if sharply struck should "ring" like a piece of dry mahogany, and I think it will be found that the dielectric losses in such a condenser, other things being equal, will be markedly less than in one giving a dull, lifeless sound when struck.

Mr. Mansbridge.

It seems doubtful, however, whether the whole of the losses can be accounted for by the "blows" referred to by Mr. Mordey; indeed, the word seems scarcely applicable in the case of a well-made condenser in which the dielectric possesses a fair amount of elasticity. On the other hand, I cannot agree with the suggestion made later in the discussion that the whole of the loss is due to the resistance of the metallic foils or coated strips. If, as suggested, any minute arcing occurs, the effect must necessarily be transient. It seems to me that if the dielectric is regarded from the point of view of a transmitter of power it will be only reasonable to expect some loss of energy in the transmission, especially as the medium has but little mechanical elasticity. In this connection it is noteworthy that mica and glass condensers have, as a rule, a lower dielectric loss than paper condensers, and these substances have, of course, a much higher coefficient of elasticity than has paper. Further, much higher dielectric losses are shown by condensers impregnated with oil than by those in which paraffin wax is used, this being no doubt due to the fact that the liquid dielectric can move under the influence of stresses set up electrostatically.

I should point out that Mr. Mordey's figure of 13 lbs. per square foot requires revision, inasmuch as the assumed thickness of the dielectric 0·001 in. is too low. The *minimum* with the sample under test is about 0·0016 in., and this reduces the mechanical pressure on the dielectric considerably below the figures quoted.

Dr. Sumpner's remarks concerning the behaviour of condensers of the coated paper type in connection with measuring instruments for "heavy" electrical engineering are of particular interest as breaking comparatively fresh ground, and I am glad to have Dr. Sumpner's testimony to the satisfactory results which he has obtained in his special field from this type of condenser. I quite agree that the Sumpner instruments are more convenient for capacity measurement than the less robust apparatus in use by the National Telephone Company, but both methods have their special advantages.

Mr. Stubbs raises a point which I had not perhaps made sufficiently clear, and I am glad to have this opportunity of elucidating it. In referring to "pinholes" in the foiled paper I had in mind holes existing in the stock prior to its being coated. During the coating process these would become filled with the metallic powder and would consequently cause trouble unless removed by the "breakdown" process. Besides these metal-filled perforations there are, however, numerous other defects or weak places which are literally "broken down" by the electrical pressure. With the old form of condenser breakdowns after manufacture were due in most cases to metallic particles or grit penetrating the dielectric. Furnace ash and abraded metal from machinery were most often the proximate cause.

Respecting the melting-point test, I should explain that the method indicated in Fig. 5 takes only a few minutes—ten at the outside—to carry out, since there is no necessity to proceed beyond the point where the temperature becomes stationary. The method in question

Mr. Mansbridge.

is that adopted by most paraffin refiners; that quoted by Mr. Stubbs, though regularly used in laboratories, was found to take more time and to be less suitable for workshop use.

The accuracy of the formula for correcting insulation to standard temperature is being inferentially checked daily, and there seems to be no reason to doubt its accuracy.

Mr. Record's criticism of the name "foiled paper" is justifiable. The name was, however, adopted because it was the recognised trade description of an existing article.

So far as the effective capacity of a condenser with alternating current is concerned, I find that for ordinary frequencies the conductor resistance in the condenser itself has very little effect. Properly made condensers of the coated paper type have been tested at frequencies up to 2,000 periods without revealing any appreciable difference in capacity as between alternating and continuous currents. To produce the best results, however, the manufacturing details referred to in the paper must not be overlooked, particularly with reference to the prevention of creases. Paradoxical as it may seem, it is a fact that rolled condensers of this type can, with reasonable care in manufacture, be made so that even after pressing they contain nothing in the nature of sharp creases.

On the motion of the President a vote of thanks was unanimously passed to Mr. Mansbridge for his valuable paper.

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